1 2 9 0

UNIVERSIDADE D
COIMBRA

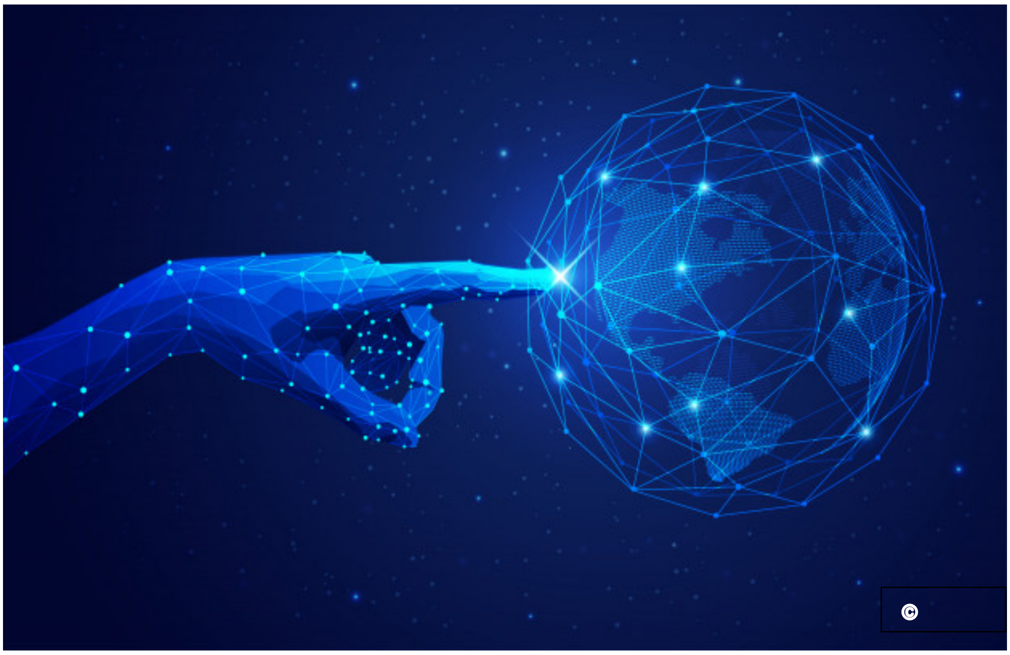
Rosa Doran

ON TEACHER TRAINING AND COMMUNITY BUILDING FOR INNOVATION IN EDUCATION: STRATEGIES TO IMPROVE SCIENCE LEARNING IN CLASSROOM

Tese no âmbito do doutoramento no Ensino das Ciências ramo da Física orientada pelos Professor Doutor José António de Carvalho Paixão e Professor Doutor João Manuel de Morais Barros Fernandes e apresentada ao Departamento de Física da Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

Setembro de 2019

On Teacher Training and Community Building for Innovation in Education: Strategies to Improve Science Learning in Classroom



Rosa Doran

2019

Faculdade de Ciências e Tecnologia da Universidade de Coimbra

Table of Contents

List of Figures

List of Tables

Glossary of Abbreviations

- ART – Aprendizagem Reforçada pela tecnologia – Technology Enhanced Learning
- BHIMS – Black Holes in My School
- CCPFC – Concelho Científico-Pedagógico da Formação Contínua - Scientific-Pedagogical Council of Continuing Education
- CERN - Conseil Européen pour la Recherche Nucléaire
- CIP-PSP - Competitiveness and Innovation Framework Programme – Policy Support Programme
- COP – Community of Practice
- CPD – Continuing Professional Development
- DAC - Domínios de Autonomia Curricular – Domain of Curricular Autonomy
- DGE – Direção Geral da Educação
- DGEEC - Direção-Geral de Estatísticas da Educação e Ciência
- DSOD – Digital Schools of Distinction
- DSOE – Digital Schools of Europe
- EACEA - Education Audiovisual and Culture Executive Agency
- EC – European Commission
- ECCG - Essential Core Curricula Guidelines
- EPFL - L'Ecole Polytechnique Fédérale de Lausanne
- ESA – European Space Agency
- ESO – European Southern Observatory
- EU – European Union
- EUHOU – European Hands-on Universe
- EUN - European Network of Schools
- FP6 – Framework Programme 6
- FP7 – Framework Programme 7
- GHOU – Global Hands-on Universe
- GO-GA – Go-lab Goes Africa
- Go-Lab - Global Online Science Labs for Inquiry Learning at School
- GTTP – Galileo Teacher Training Program
- H2020 – Horizon 2020
- HOU – Hands-on Universe
- IASC – International Astronomical Search Collaboration
- IBL – Inquiry Based Learning
- IBSE – Inquiry Based Science Education
- ICT - Information and Computing Technologies
- IFTF – Institute for the Future
- ILS – Inquiry Learning Space
- INCODE.2030 - Iniciativa Nacional em Competências Digitais e.2030
- ISCED - International Standard Classification of Education
- ISE – Inspiring Science Education
- IYA2009 – International Year of Astronomy 2009
- MPC – Minor Planet Centre
- MOOC – Massive Online Open Course
- NAS – National Academy of Science
- NEC – National Expertise Centre
- NEE – Necessidades Educativas Especiais
- NEXT-Lab - Next Generation Stakeholders and Next Level Ecosystem for Collaborative Science Education with Online Labs
- NGO – Non-governmental Organization
- NOAO - National Optical Astronomy Observatory
- NUCLIO – Núcleo Interativo de Astronomia

- OCW – Open Course Ware
- ODS – Open Discovery Space
- OECD - Organisation for Economic Co-operation and Development
- OER – Open Education Resources
- PACF - Project for Autonomy and Curriculum Flexibility
- PBL – Project Based Learning
- PISA - Programme for International Student Assessment
- PLATON - Promoting innovative Learning approaches for the teaching of Natural Sciences
- ROSE - Relevance of Science Education Project
- RRI – Responsible Research and Innovation
- RXTE - Rossi X-ray Timing Explorer
- SDG – Sustainable Development Goals
- SELFIE - Self-reflection on Effective Learning by Fostering the use of Innovative Educational technologies.
- SPA – Sociedade Portuguesa de Astronomia - Portuguese Astronomical Society
- STEAM – Science, Technology, Engineering, Arts and Mathematics
- STEM - Science, Technology, Engineering and Mathematics
- TALIS - Teaching and Learning International Survey
- TEL – Technology Enhanced Learning
- TIC – Tecnologias da Informação e da Comunicação
- TIMSS - Trends in International Mathematics and Science Study
- TRA – Teachers Resource Agent
- UNESCO - United Nations Educational, Scientific and Cultural Organization
- WILL - Working with Inquiry and Interdisciplinary Learning

Abstract

The lack of student interest in science topics is a growing problem worldwide. In an era where technology invades our lives, where artificial intelligence becomes more and more a part of our daily experience, expertise in these fields and awareness about future opportunities are key components in the preparation of young generations. In order to spark their interest in STEM (Science, Technology, Engineering and Mathematics) subjects, and to increase their motivation and self-awareness of their capabilities, students need to be exposed to modern science, to have minds-on and hands-on research. Active and engaging learning has to be used as a means to promote the acquisition of key competences while improving their content knowledge repertoire. In order to achieve this vision it is necessary to empower educators to improve their competence profiles and to enable them to embed this vision in their daily teaching. Educators need to learn how to use and feel confident and supported in integrating modern methodologies in the classroom. They need to assume the role of facilitators of learning and become travel companions to the future leaders of our planet.

In this research several approaches were explored starting from outreach activities, moving to scientists bringing real research to the hands of students, continuing to teacher training and support, and finally the creation of the five pillars of community building.

By collecting data related to the different actions and approaches it was possible to find compelling evidence showing that outreach activities, although very important, are confined in time and space and hard to replicate in schools. Bringing science to schools and engaging students in real research seems to have a relevant impact in their attitudes toward science and can leave behind long-lasting impact, however these actions are also not sustainable and are very difficult to replicate. Training teachers seems to result in more meaningful learning opportunities for students and improves the competence profile of the teacher. However, even after receiving training, teachers manifest insecurities towards implementing research in the classroom compromising the applicability of the approach. The implementation of the **5 pillars of community building** (ensuring the engagement of teachers as partners and not as simple trainees, providing multiple training opportunities in various different formats, ensuring a strong support strategy is in place, recognizing their efforts and facilitating the emergence of a community of practice) and the addition of a specific **competence profile for teachers** presented the first evidences of classroom applicability and sustainability of science research in the classroom.

In conclusion, bringing innovation to classrooms and leveraging the competence profile of educators to integrate current trends in science research and technology is not an easy task. It requires the existence of a proper strategy, a vision and a concerted effort to further the acceptance of the mission to ensure the vision is materialized. The investment in the competence profile of teachers and in their continuous support is key for the guarantee of a brighter future for generations to come.

Keywords: science education, teacher training, community building, innovation in education, research in classroom, inquiry based learning, interdisciplinary learning

Resumo

A falta de interesse dos alunos relativamente a tópicos da ciência é hoje em dia um crescente problema a nível mundial. Numa era em que a tecnologia faz parte integrante das nossas vidas e a inteligência artificial se torna cada vez mais comum nas nossas experiências diárias, o conhecimento nestas áreas e a consciência sobre oportunidades futuras são componentes chave na preparação das novas gerações. De forma a despertar o seu interesse nas áreas STEM (Ciência, Tecnologia, Engenharia e Matemática), aumentar a sua motivação e a sua autoconsciência sobre as suas capacidades, os alunos precisam de ser expostos à ciência moderna de uma forma *minds-on* e *hands-on* na investigação. A aprendizagem ativa e envolvente deve ser usada de forma a promover a aquisição de competências-chave e enriquecer o seu repertório de conhecimento. De forma a alcançar esta visão, é necessário capacitar os professores, melhorando o seu perfil de competências e dar-lhes a oportunidade de incorporar esta visão na sua prática diária. Os professores devem aprender como usar e sentir-se confiantes e apoiados para integrar metodologias modernas na sala de aula. Devem assumir o papel de facilitadores da aprendizagem e tornar-se companheiros de viagem dos futuros líderes do nosso planeta.

Na presente investigação, várias abordagens foram exploradas, desde atividades de divulgação cientifica, a visita de cientistas às escolas, trazendo momentos de investigação cientifica à sala de aula, envolvendo os alunos em atividades *hands-on*, até à formação e apoio aos professores e finalmente, a criação dos cinco pilares da formação de uma comunidade de prática (*the 5 pillars of community building)*.Ao recolher dados relacionados com as diferentes abordagens foi possível encontrar evidências que indicam que as práticas de divulgação científica, embora muito importantes, encontram-se confinadas no tempo e no espaço, sendo difíceis de replicar em sala de aula. Trazer a ciência para a escola, envolvendo os alunos em investigação científica demonstra ter um importante impacto nas suas atitudes em relação à ciência, podendo causar um efeito de longa duração; contudo, estas ações também não são sustentáveis e podem ser difíceis de replicar. A formação de professores, demonstra resultar em oportunidades de aprendizagem mais relevantes para os alunos e melhorar o perfil de competências dos professores. Contudo, mesmo depois de receberem formação estes manifestam insegurança relativamente à implementação de investigação em sala de aula, comprometendo a aplicabilidade da abordagem. A implementação dos cinco pilares da formação de uma comunidade de prática (garantir o envolvimento dos professores como parceiros e não como apenas formandos, proporcionar diversas oportunidades de formação em vários formatos distintos, garantir a existência de uma forte estratégia de apoio, reconhecer os seus esforços e facilitar a criação de uma comunidade de prática) em conjunto com um perfil específico de competências do professor, apresentou as primeiras evidências de aplicabilidade em sala de aula, assim como de sustentabilidade da integração de investigação cientifica na escola.

Concluindo, levar a inovação à sala de aula e elevar o perfil de competências dos professores de forma a integrar as tendências atuais na investigação científica e tecnológica, não é uma tarefa simples. Requer a existência de uma estratégia apropriada, uma visão e os esforços necessários para levar a cabo a missão, garantindo que a visão se materializa. O investimento num perfil de competências dos professores e num apoio continuado parece ser a chave para garantir um futuro brilhante para as gerações futuras.

Keywords: Ensino das ciências, formação de professores, comunidades de prática, inovação em educação, investigação na sala de aula, aprendizagem baseada em *inquiry*, aprendizagem interdisciplinar

"... the teacher's task is first to nourish and assist, to watch, encourage, guide, induce, rather than to interfere, prescribe, or restrict."

Maria Montessori

Introduction

The world is evolving at a fast pace. The 21st century arrived and with it brought the tools that accelerated development with a speed never seen before. Such tools, namely those related to technology, allow for the wide and fast spread of information, providing tremendous opportunities for the progress of important fields such as Science, Medicine, Technology, etc. However, it can also pose a danger for those not skilled enough to filter valid information from trustable sources. It is as easy to search the web for information as it is to create information and spread it. Lack of science literacy can lead to the dangerous dissemination of biased information and the creation of ill-informed communities. Some of the main threats that have been materializing today are, for example, the anti-vaccination movement, the flat-earth believers, etc. (Goertzel, 2010).

Considering that one of the main measures to prevent such dangers in today's world is the development of scientific literacy among communities, this thesis aims to target one of the strongest tools to achieve it: young people's education. Science literacy can be understood throughout this document as: "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen" (OECD, 2016b). While this is the most important factor in promoting the development of an informed and sustainable society, we are also experiencing a lack of student's interest in scientific topics at school as well as for science careers.

The distancing of the public in general from science and the widespread impoverishment of scientific literacy is not new and is currently considered a worldwide problem (Osborne & Dillon, 2008). Osborne and Dillon clearly identify the failure of the education system to create the roots for future generations of scientists. The report suggests a rethinking of science education in order to be more appropriate and integrated with the reality surrounding students.

The Rocard report, prepared by request of the European Union, (Rocard, 2007) suggests a number of innovative measures to reverse the growing lack of interest of students in scientific subjects. One of the main recommendations of the report is the introduction of the Inquiry methodology for science teaching and the focus on the professional development of teachers.

Following these important documents, a number of initiatives were launched by the European Union, under the 7th Framework Programme, to test the introduction of innovative methodologies for science teaching, namely Inquiry Based Learning (IBL). Some of these initiatives and their results are presented in this thesis (Go-lab, 2012; ISE, 2013; ODS, 2012, etc.).

Taking into account these (and other) already tested and validated initiatives, this thesis describes in detail the steps that are necessary to facilitate the integration of modern science and the use of real research experiences in the classroom. It describes various aspects of knowledge creation and the relevance of student-centred methodologies when the aim is to have innovation and science fascination invading young minds. The importance of the participation of different stakeholders will also be highlighted and the various facets of professional development when a whole community is engaged will be described.

For this research the aim was to evaluate the impact of a series of actions, involving several different stakeholders, from scientists to trainers, to teachers and finally to the end user, students. The actions presented here integrate the use of cutting-edge technology for the teaching of the sciences, such as robotic and virtual laboratories, and interactive platforms for

the reproduction of scientific experiments, from the construction of hypotheses to the final presentation of results.
After a review of the state of the art in the field of science education and the panorama of schools' settings to accommodate innovation in education given in **chapter 1**, an overview of the importance of science outreach and education as a vehicle of democracy will be presented. A few examples of high impact activities for the promotion of science, such as the International Year of Astronomy 2009, are presented in **chapter 2**.

Considering the people's natural curiosity towards some advances in research fields such as Astronomy, Space Exploration, Genetics, etc., it is natural to consider that the involvement of students in such research experiences would greatly amplify their interest in STEM (Science, Technology, Engineering and Mathematics) subjects. A few examples are presented in **chapter 3**.

Once success stories start emerging, from the engagement of scientists with schools and the very positive results attained, the next natural step is to prepare teachers and facilitate the appropriate tools and resources to reproduce some iconic experiments such as: black hole discoveries, asteroid search, detection of particles at CERN, etc. Some methodologies to train educators and associated tools are presented in **chapter 4** and a more in-depth example of exploration of a scientific research on the field of stellar mass black holes is presented in **chapter 5**.

Chapter 6 presents the steps for a successful strategy to empower educators to go the extra mile and leave their comfort zone towards the implementation of modern science research in the classroom. The creation of a competence profile for educators and the creation of the 5 pillars of community building are described as guidelines for a successful journey from scientists to students.

Finally, **chapter 7** is devoted to tips and tricks to introduce innovative methodologies in the classroom while ensuring teachers are acquiring the necessary key skills to integrate them in their practices. The document ends with some reflections on what is necessary to ensure the next generation leaves school with the basic competence profile to be ready and eager to embrace 21st century challenges.

The details about the Methods and Data Acquisition used in this thesis is described in Appendix XI. My role in the various projects is presented in Appendix XII.

The research presented in this document is very relevant in a time where changes in education systems all over the world need to happen at a much faster pace, to accompany the fast evolution of technology, business and life itself. Artificial intelligence, manned missions to other planets, genetic engineering, among other similar topics are no longer science fiction, they are not even the future, they are the present and they are creating new jobs and opportunities at a very high rate. It is estimated that 85% of jobs that will be existing in 2030 (when the current students will be leaving school for the labour market) don't yet exist (IFTF, 2017)) . Preparing students to embrace this reality is an emergency. The main target is certainly the students, but in order to reach them we need to empower their teachers and enlighten their communities. For this reason, the main focus of this document is them, the facilitators of the future, the teachers.

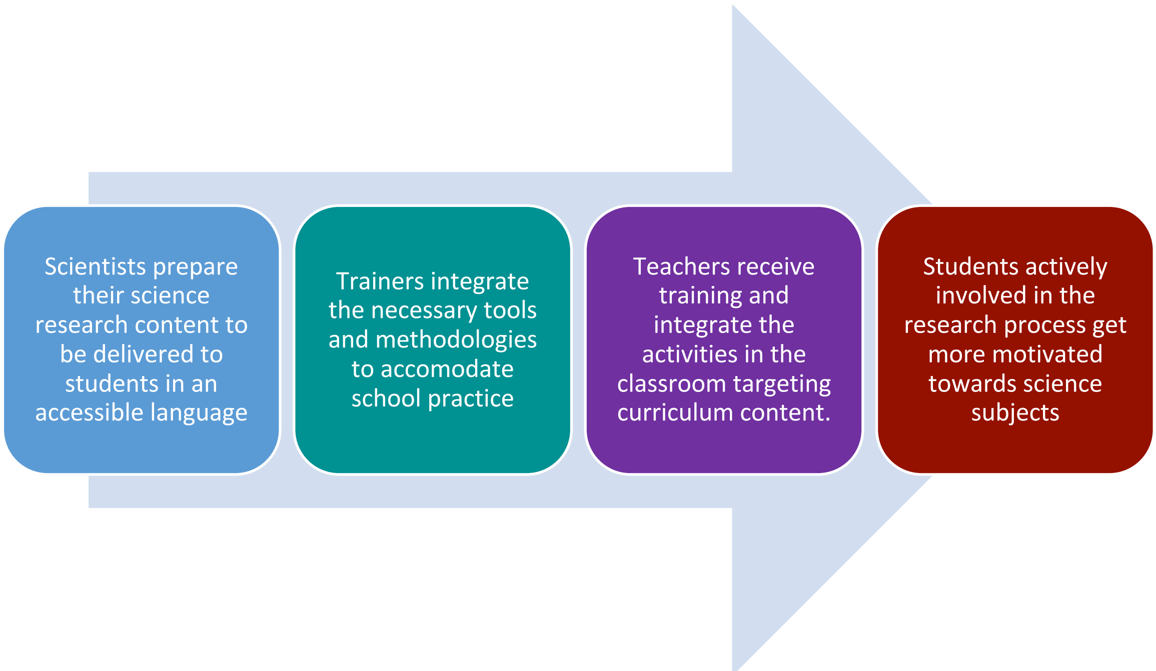
Research Questions

The proposed research had several interconnected components that varied throughout the process. At the beginning, the aim was to evaluate the impact of the implementation of a research activity in the classroom in motivating students to learn science. The initial scheme proved to be much more complex than initially expected so the research had to shift to a narrower focus.

The working hypothesis for this research was the following:

Hypothesis – When scientists produce resources for students related to their research in a user-friendly language and this material is associated to the necessary tools and methodologies to be delivered in teacher training events, teachers will feel confident to integrate them in their lessons, while following curriculum content and actively engaging their students in the research process.

This hypothesis contemplates the following scheme:



This hypothesis is very complex and can't be answered with a straightforward research experiment. It encompasses several different building blocks, each of them giving rise to a specific question:

1) The work of scientists as promoters of their research to the public in general and its impact → **What is the impact of science outreach as a mechanism to bring modern research to everyday lessons?**
2) The work of a scientist that acts as a partner of schools and brings their research directly to the hands of students → **What is the impact of scientists working directly with students by involving them in hands-on experiences about their research topics?**

3) The mission of teacher trainers to aggregate scientific knowledge with the necessary methodology to ensure its usability in classrooms and during the preparation of educators → **What is the impact of teacher training to the integration of modern research in their classes?**
4) The role of the teacher as facilitator of learning → **What is the impact of a trained teacher on the motivation of students for science subjects?**

In order to answer these questions, a series of current practices related to each of the above-mentioned building blocks were described, and data about their impact was collected and analysed in order to answer the questions.

1. State of the Art

The research reported in this document was conducted in two distinct phases. During the first phase (between 2011 and 2016), when the majority of results were collected, Portugal had a strong focus on content-based curricula as directives of the Ministry of Education and the major factors for assessment relied on summative tests and exams. The second phase, with a new Ministry of Education (with effective changes from 2017 onwards) witnessed a significant shift. As part of that shift, the competence profile of students when leaving school (Martins et al, 2017) became a key focus of schools and the vision of education authorities is now focusing on a series of actions structured under the roadmap for citizenship, published in 2017 (DGE, 2017). Several measures provide more autonomy to schools, flexibility of the curricula and the overall model leans strongly to the constructivist approach. More on this point will be presented later in this chapter.

This work focuses on the promotion of science as a tool to prepare students for a fairer and more sustainable future. It also focuses on the use of ICT (Information and Computing Technology) as important supporting tools, something that cannot be ignored when we are preparing new generations for the future labour market - and the future is hard to predict. Scientific knowledge and practices, that are based on a universal language promotes development that benefits everyone - or at least it should. Science requires collaboration, sharing, fosters key skills and empowers free thinkers

1.1. Key Competences for the 21st Century

According to UNESCO (Delors, 1996) the four pillars of education are: "Learn to know"; "Learn to do"; "Learn to live together" (learning to live with others) and "Learning to be". These pillars form the fundamental structure for an individual in the 21st century. However, these four pillars of learning are under threat in the context of current societal challenges (Unesco, 2015). Our planet is desperately in need of a more humanistic vision of education. Students need to acquire key competencies such as the ability to use critical thinking, a knowledge that cannot be prescribed in a syllabus but acquired in a contextualized way, integrating the existing challenges and opportunities surrounding each individual and institution. The same document stresses the need for a humanistic curriculum, one that raises more questions than provides answers. A fair and strong curriculum should promote respect and understanding for diversity, encompass intercultural education and embed universal values. Education has to be inclusive and respectful of both gender and cultural equality.

Schooling as devised for the industrial revolution is no longer suitable. And pockets of resistance towards traditional teaching and learning models are growing disturbingly at a global level. Movements such as "unschooling" (Gray & Riley, 2015) or "home schooling"(Morton, 2010) (home education) are gaining more and more supporters. Ideally both could be considered a fair way to promote a very rich learning experience. But we also find many examples of unprepared parents trying to replace an education system they don't agree with. The need to rapidly change schools to a more modern environment is upon us.

ICT integration in classrooms is no longer a desirable change, it is a mandatory part of preparation of students for the world of work. It is inconceivable that students nowadays are being prepared to embrace a future where robots and artificial intelligence inhabit our daily lives without acquiring the necessary expertise to understand and use their benefits. In a world swamped with fake news or simply flooded with low quality information it is imperative to be equipped with critical thinking capabilities. In a world that provides more and more degrees of freedom toward innovation and its integration in our daily lives, creativity is not desirable, it is a requirement. Problem solving skills, resilience and lack of fear of failure are the bone structure for the future leaders of our species.

Handling data, problem solving, proposing creative solutions based on artificial intelligence knowledge are some of the skills that need to be fostered, tailored and integrated in the schooling experience of learners.

The European Commission (EC, 2007) recommends the following key competences for lifelong learning as a combination of knowledge, skills and attitudes:

- Communication in the mother tongue;
- Communication in foreign languages;
- Mathematical competence and basic competences in science and technology;
- Digital competence;
- Learning to learn;
- Social and civic competences;
- Sense of initiative and entrepreneurship; and
- Cultural awareness and expression.

In (EC, 2018) a very relevant mention to this documents appears stating that when these recommendations were published many of today's jobs didn't exist yet, and this reality will continue to repeat itself at a faster and faster pace. Several important institutions including the OECD, World Bank and DELL are claiming that 80% to 85% of jobs in 2030 have not been created yet and more than 50% of existing jobs will no longer exist (Bourne, 2018) .This reality has direct impact on the educational life of today's students - this is their future we are talking about. In any future scenario, in fact already in the present, 90% of all jobs require some level of digital skills (EC, 2018c). Yet 1/5th of European students have insufficient proficiency in reading, mathematics and science. The same paper refers to the fact that many young people lack appropriate digital competences.

Globalization is a reality that is upon us with views on its advantages and disadvantages dividing opinions in Europe. Globalization directly affects the future of students, their perspectives and the requirement to thrive in a globalized world. It touches areas such as trasportation, energy, agriculture/food, telecommunications, distribution, financial services, factory production, etc. To be ready for globalization students need high quality education as this is foreseen to be a powerful way of redistributing wealth in a society (EC, 2017).

At a national level, the intended student competence profile when leaving compulsory schooling (Martins et al., 2017) is a materialization of the competences outlined above. Different countries in Europe have adopted and adapted the concept using other important documents such as P21 framework[1] and PISA 2018 Global Competence[2], as an inspiration. All of them have one reality in common: Education needs to incorporate a whole new approach for the relationship between teachers, their students and the whole community where the school is embedded.

[1] www.p21.org/our-work/p21-framework
[2] http://www.oecd.org/pisa/pisa-2018-global-competence.htm

In (EC, 2018) an update of the key competences was release with a slight change in its text as follows:

- Literacy competence;
- Languages competence;
- Science, technological, engineering and mathematical competence;
- Digital competence;
- Personal, social and learning competence;
- Civic competence;
- Entrepreneurship competence; and
- Cultural awareness and expression competence.

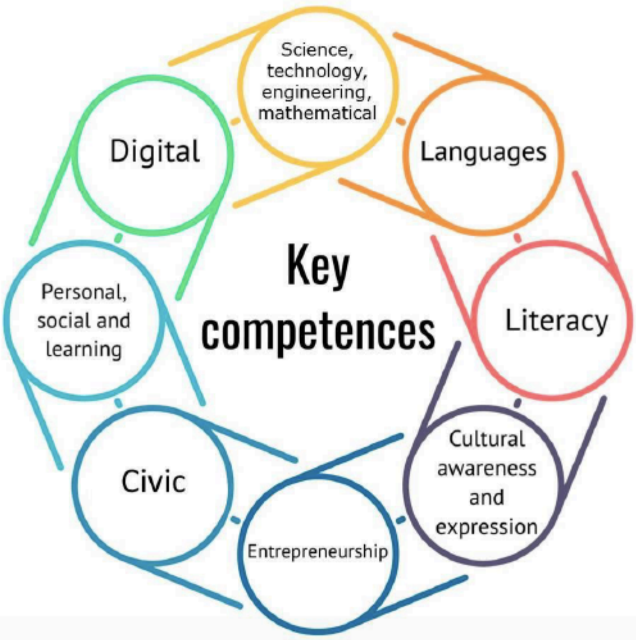


Figure 1 EU Key Competencies for Lifelong Learning 2018

These competences for lifelong learning (Figure 1) are built on strong concepts such as sustainability, European common values, gender equality and equal opportunities, openness to cultural diversity, creativity and innovation, and media literacy. This vision works directly with other important goals such as the United Nations Sustainable Development Goals (SDG) for the Millennium[3] and requires competences such as science literacy, citizenship awareness and entrepreneurship. It requires interdisciplinary and intercultural understanding as well as collaborative skills, effective communication, critical thinking, problem solving and initiative-taking, empathy, compassion, tolerance, resilience, among other importance soft skills. Aspects such as inclusion, gender equality and fairness can no longer be overlooked. The SDG suggests fruitful exchange of views and ideas between individuals and groups from different cultures leading to a deeper understanding and inevitably leading to a global perception of things. Media literacy in a digital era is mandatory. Individuals need to be able to access and critically select news, evaluate reliability, completeness, safety and privacy. Being able to validate sources and content, and being respectful to each other's freedom. **Literacy** and **foreign languages** are certainly key pillars of one's education.

[3] https://sustainabledevelopment.un.org/sdgs

The self-sufficiency of a nation depends on the competences of its citizens. Educated decisions can only be taken if people are properly informed and have basic literacy in all areas of knowledge. Expertise in key areas such as STEM (Science, Technology and Mathematics) are necessary so nations are not held "hostage" to other nations due to the inability of taking proper decisions or finding local solutions for existing challenges. Lack of interest of young students in the field of science is not new and it has been a concern for policy makers and global leaders for quite some time (Tyler, R & Osborne, J., 2012). It presents a very worrying frame if we consider that we are already in the big data era, where ICT is omnipresent in our daily lives, artificial intelligence surrounds us, and more and more innovation brings limits to our possibilities. **Digital competences** in training and learning are of uttermost importance. As presented in (EC, 2013) new ways of learning and teaching, and sharing tools, resources and best-practices are required. Teachers, as professionals, need to be properly recognized and the floor must be given to their innovation potential to target the shortage of skills and knowledge already upon us.

Training and supporting educators are key and have to be part of any roadmap towards the future. Not a traditional teacher that simply replaces a book or engages students with entertaining slides. We need teachers as facilitators of learning, as travel companions that walk the learning read alongside students. There is no recipe for this roadmap, there are no instructions to set the pavement, the roadmap is individual and has to be designed on a daily basis by each student.

There can be no learning where there is no tolerance, understanding, solidarity. Societies that focus on their own, lack global perspective. There can be no future for humankind without individuals that value humans independently of their colour, cultural/religious background and gender. Freedom is only for those with a strong cultural background, open minded individuals that embrace diversity as a prosperous enterprise. Being able to develop listening skills, empathy and the capability of understanding each other's perspectives will eventually be the key to our survival and the solution of many challenges our planet is now facing. **Civic competences** are these and so much more.

Entrepreneurship is no longer a word that enters our jargon only when we leave school. Students with open minded teachers are already creating innovation at an incredible pace. In Portugal, at the national selection for the participants of the Science on Stage Festival a parade of talents was presented. Students proposing apps that monitor the health of firefighters while they are fighting for our safety, gloves that quickly monitor the basic indicators of the body in case of an emergency, self-sustainable houses, among other amazing activities were presented. The world of work is already invading schools, and training and learning is acquiring a completely new meaning[4].

Cultural Awareness and Expression Competence is a means for students to express their views and understanding of the world. Multiple ways of viewing and understanding the world can only enrich the final outcome. Creativity starts by creating the space for innovative solutions to diversify and multidisciplinary problems can emerge. Visual thinking strategies are our natural way to understand the surrounding world. When we provide the means by which these can be easily expressed self-imposed barriers become meaningless.

[4] https://www.facebook.com/events/1548321778569563/

The challenges at hand are serious. How to bring this important framework to the daily lives of our students? How to empower educators to embrace this quest? In this thesis I argue that proper training and support are part of the solution.

In (EC, 2016) there are interesting highlights such as: *'There's never been a better time to be a worker with special skills or the right education, because technology can be used to create and capture value"*. This document clearly states that the world of work is heavily influenced by globalisation and no longer a static concept.

The E2030 position paper on "The future of education and skills" (OECD, 2018d) presents a whole new view of education based on the construction of knowledge, skills, attitudes and values (Figure 2)

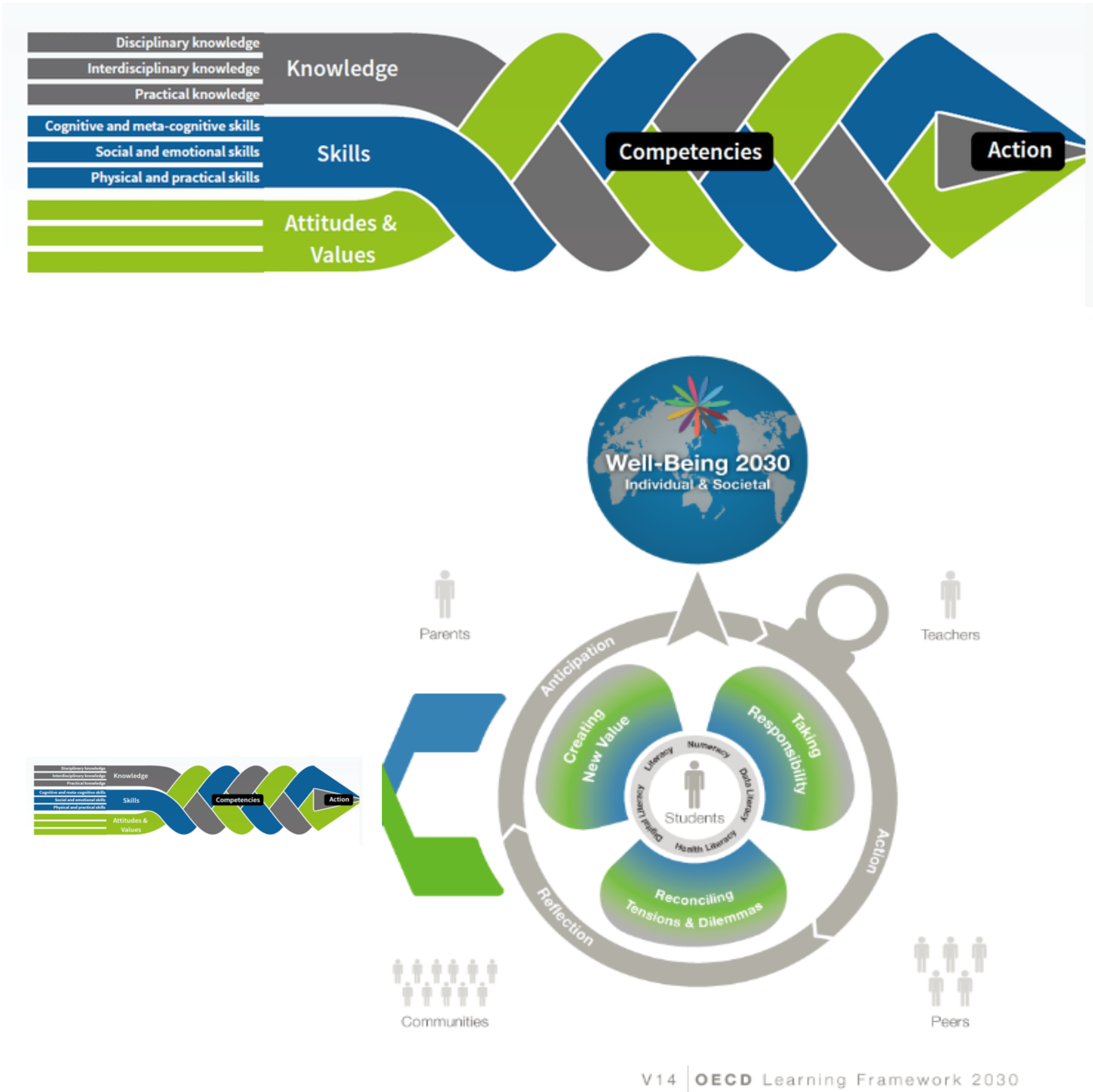


Figure 2 OECD Learning Framework 2030 (Competencies as the integration of knowledge, sills, and attitudes &values)

This vision advocates that students need to be recognized as individuals with unique capabilities as well as take into consideration their wider settings, i.e., the community where they live, teachers, peers, families etc. Targeting the communities or benefiting from them should also be part of the education of students. Students should have access to personalized learning environments that take into consideration their personal strengths and frailties and teach them how to benefit from their own communities. They should be provided with different learning experiences and be responsible for their own learning path. They should receive a solid digital and data literacy to be prepared for the world of work.

1.2. Digital Competencies for a Digital Planet

Shifting from the traditional expository model, where teachers comfortably deliver content to students that are not at the centre stage, to a competence-based education requires a lot of effort and good will. This requires teachers and students alike to step out of their comfort zones. Educators need to engage in continuing professional development (CPD), schools need to adopt a different organization model, there has to be support and collaboration among all teaching staff of the school, parents need to be supportive and students need to be open to the new proposal, amongst other challenges.

Teachers of diverse domains need to acquire basic digital skills (Redecker & Punie, 2017), they have in their hands the important task of transforming students (the so called digital natives) into competent users of what technology has to offer. Schools and educators need to discover what the status of their schools are and develop their own maps towards innovation. Several tools are being developed and made available for schools as teachers (Digital Schools of Europe Self Reflection Tool – presented in this thesis, SELFIE – The European Commission Self Reflection Tool for Schools[5], OECD Survey to support the creation of effective Learning Environments (OECD, 2018b)

The emergence of digital technologies brought a revolution to our lives, maybe more than once. With it also came the so-called Digital Divide, the divide between those with access to ICT tools, resources and education for its use, and those where this is not yet a reality. But the divide is becoming more evident and mobile devices are reaching out to more distant and rural populations. The problem is what to do with it? How can educators facilitate the learning of how to use such devices as a source of knowledge and development if they, sometimes, don't even know where to start. Here, again, community building and support is the key to find local solutions to global problems.

But ICT is also endangering schools and universities refusing to accept that their model has to change (Unesco, 2015). It is not difficult to predict their death if nothing changes. Major universities across the world are making their courses freely available online, the same happens to renowned schools across the globe. Suddenly the "walls" between the countries are disappearing and access to distinguished schools is at a distance of a click. One can even dare to ask: "What would happen to education if employers stopped asking for diplomas?", "What if in the world of work, it makes no difference where or what you learn, what matters is the competences you have?"

So clearly changes are necessary and urgent and there is no other way rather than migrating to a new model of education, one that accommodates the future as if it is today. Teachers need

[5] https://ec.europa.eu/education/schools-go-digital/about-selfie_en

to be empowered to embrace innovation, to develop their abilities to accommodate diversity and to understand that everyone has a special need. They need to accept that learning is a lifelong enterprise. **A teacher saying that they refuse to get training if the government is not paying for it or if it doesn't bring progression to their career is the same thing as a doctor refusing to update their knowledge. Would you go to a doctor that has not received any training in 20 years? And yet we let educators who are not willing to update their knowledge educate our children.**

The digital planet made the world a small place. Generations should understand that we live in a global community where diversity is our richness. Responsible citizenship is a right and obligation for us all.

As defined in (Unesco, 2015), knowledge can be understood as encompassing information, understanding, skills, values and attitudes. Competences refer to the ability to use such knowledge in given situations. Knowledge and competencies are what allow us to understand the trends of the future, and what is necessary to follow it and make the most out of the emerging opportunities. The world is a much better place now than it was before and with better education it will be even better[6].

1.3. Assessment

Assessment can be a means to increase awareness of one's learning processes and needs, and help overcome obstacles to learn more effectively (EC, 2018c). It can be a means to assist individuals to understand their preferred means of learning and even become self-tutored developers of their own learning path. For teachers acting as facilitators or tutors of learning, it's a means to understand the specificities of each student and as such tailor the support required by each learner. It is easy to understand that goals need to be individualized and success measured against one's personal challenges and individual special needs.

Self-regulated adults with self-awareness have to be capable to use self-assessment tools to identify their learning outcomes, challenges and specific needs. These are key aspects of a person that is ready for a life-long learning enterprise.

Countries have different ways to measure the level of their educational systems. Commonly international tools such as PISA and TIMSS are used to evaluate and compare the level of different education systems. Each have their benefits and shortcomings but presenting the full comparison goes beyond this thesis. The OECD and the European Commission are currently working in order to better integrate the competences component with a higher strength in their assessment efforts. In Portugal, for example, according to PISA 2015[7] the indicators are very inspiring showing that in comparison to the OECD average:

- Portugal has a better performance both in reading and science, and in mathematics it is close to the average,
- the performance in science, maths and reading have been continuously improving since 2006,
- And finally, the share of top performers is increasing and the low performers decreasing.

[6] https://www.youtube.com/watch?v=jbkSRLYSojo&feature=youtu.be and https://www.gapminder.org/whc/
[7] http://www.oecd.org/pisa/pisa-2015-portugal.htm

These are some of the indicators reported in this study but a lot of the results still have to be carefully analysed and properly contextualized.

In 2010 the results of the ROSE study (Sjøberg & Schreiner, 2010) brought some other relevant data that was not immediately visible in the PISA and TIMSS results. As a fierce critic of these studies, Sjoberg highlighted some statistics coming from these studies that reveal, for instance, that the same countries where students are top performers in science also show very a low interest in science combined with an unhealthy attitude to science. Arguably, when assessing students, we are not revealing the full picture and not taking a holistic understanding of what is really important for societies and their future. The study presents several interesting statistics about the preferences of students related to science topics. The most popular topic for both girls and boys is Space and the possibility of life outside Earth, despite their opinion being that science classes are not ok, are less interesting than other subjects, do not increase career opportunities or appreciation for nature, do not increase curiosity, etc.

When we think about education the future is always the main goal. Like it or not, with good or bad aspects, globalization is here to stay. Globalization brings innovation, new experiences and higher living standards (OECD, 2016a). But it also increases the digital divide, worsens inequalities and provokes social division. On a small planet like ours having political boundaries is something that challenges our values and puts in place our real morals and attitudes. Countries self-nominate themselves as owners and masters of fractions of a planet that from the sky shows no borders except for the natural frontiers such as mountains and rivers. The way humans self-organize needs to be re-considered and taken in the new light of a global world. The rise of populism and nationalism, and the lack of voters' critical thinking across the globe is very frightening and strengthens the urgent need for better education, more critical thinking and global awareness. All of this requires a new preparation of new generations where collaboration, tolerance, solidarity, cultural differences and acceptance must be in place. The existence of such values and attitudes is now being integrated in the new PISA assessment, reflecting also the OECD education 2030 framework. This initial step has the potential to inspire countries to adopt methodologies centred on the student and focusing on their communities - some of the methodologies being suggested in this thesis.

1.4. Teaching and Learning

Teachers need to understand that in these changing times their role has to shift from content deliverers to facilitators of learning. In (Gilbert, 2010) we find a very nice description of how teachers have acquired a more demanding and challenging role now that so much information is available on our portable devices. Knowledge is no longer a privilege of a few, nor is it restricted to those with access to schools. It is available freely to anyone with some kind of connectivity. Teachers' roles are now as facilitators and schools have to be the community hub where learners and facilitators find the best ways to promote the learning experience of each individual. New times, new tools, new challenges, new opportunities make it imperative to find new ways to structure the institutions of knowledge and competence development. According to (OECD, 2018e) a teacher is a group leader, that tries to understand the students' specific needs.

Teachers need to equip students with the necessary competences to embrace an unpredictable future. Never before has Technology Enhanced Learning been so important and thus it is necessary to have the knowledge of how to use it to its full potential. Students will have to learn how to work in an interconnected world. They will need to be capable of collaborating respectfully with people from all cultural backgrounds, and deal equally with students of different genders and social environments. They will have to understand that their actions can have a huge impact and that they are part of the solution and insurance of mankind's collective wellbeing. School is no longer about solely learning content - this has become just one of the many aspects a school is responsible for. Teachers are the ones in charge of building appropriate learning environments and ensuring the different needs of each student are accommodated (Schleicher, 2018).

Usually in my presentations to teachers I give the following example: If a talented surgeon from the 19th century was frozen in time and suddenly woke up in our world, would they be performing surgery? What if that person was a teacher instead of a doctor? Most people are immediately against the idea of the doctor performing surgery and are surprised by the fact that they have probably never really carefully considered the option for the teacher. Indeed, going to certain schools somehow seems like travelling to the past without all the fun of it. Times change fast and education has to change accordingly.

We know what the necessary competences are, we have a fair collection of methods and ideas to integrate innovation in education, we are aware of why there is such an urgent need and we have tips on how to assess innovative ways of teaching and learning. Yet the reality between what we know and what is currently happening in schools is huge (NAS, 2015) .

Learners (teachers and students) should be recognized and appreciated for their unique characteristics. Each individual has their own learning style (Merchant, 2004). People can be visual learners, prefer auditory stimulation or feel more comfortable with kinaesthetic activities. When discussing the different competences, a learner has to realize that these specific characteristics should be taken into account and be aware of the specific competences that will enable students to pursue their individual objectives, satisfy their personal interests and aspirations. What are the necessary skills to allow them to become active citizens in society?
In 2015 a very important document was published by the European Commission (EC, 2015) with key recommendations related to science education and its importance to society:

- Science education should be an essential component of a learning continuum for all, from pre-school to active engaged citizenship,
- Science education should focus on competences with an emphasis on learning through science and shifting from STEM to STEAM (Science, Technology, Engineering, Arts and Mathematics) by linking science with other subjects and disciplines,
- The quality of teaching, from induction through pre-service preparation and in-service professional development, should be enhanced to improve the depth and quality of learning outcomes,
- Collaboration between formal, non-formal and informal educational providers, enterprise and civil society should be enhanced to ensure relevant and meaningful engagement of all societal actors with science, and increase uptake of science studies and science-based careers to improve employability and competitiveness,
- Greater attention should be given to promoting Responsible Research and Innovation (RRI) and enhancing public understanding of scientific findings and the capabilities to discuss their benefits and consequences,
- Emphasis should be placed on connecting innovation and science education strategies, at local, regional, national, European and international levels, taking into account societal needs and global developments.

The document elaborates at great depth on the importance of science education to prepare citizens for well thought and well-structured/reasoned decision-making processes. To ensure nations have the manpower to actively participate in the increasingly complicated technological world, to properly prepare citizens to lead personal and professional engaged lives, to inspire and motivate students of all ages to pursue a career in science, to empower responsible participation in public science conversations, debates and decision-making processes. This document became a reference for all projects in the framework of H2020, more specifically for the field of Science and Society.

As stated in (OECD, 2018e) teaching quality is a difficult concept to measure. A properly built assessment strategy can help evaluate the impact and efficacy of the pedagogical model and strategies used by teachers. According to the same document, PISA is consistently showing that student-centred models have a positive effect on students learning and motivation.

1.4.1. Training Educators – Continuing Professional Development as a Tool for a Fair and Sustainable Future

Educators have a major role in defining the future of humankind, supporting and facilitating learning and emergence of talents - preparing future generations for the challenges ahead. More is required from them in terms of student outcomes, in having more diverse and fair classrooms, integrating ICT innovation and accommodating the individual needs and talents of learners. Policy makers have to provide the necessary support at a national level and school/local communities have to also take responsibility for this important task. Failure in supporting and preparing educators is the failure of us all. Several countries in Europe face a shortage of teachers (not the case of Portugal), specifically in STEM areas. The aging of the teacher population is also something that has to be taken into account when designing professional development opportunities.

Across Europe there are different requirements for a person to become a teacher. Half of European countries have only the successful graduation from initial teacher training as a requirement. This applies, for instance, to Portugal and Finland. Furthermore, around three quarters of European educational systems have open and decentralized systems for recruiting teachers. The remainder have a centralized process, as is the case in Portugal (EC,2018d). The competence profile of teachers is defined in various ways in the different educational systems, and continuing professional development is strongly encouraged. In Portugal, for instance, it is mandatory and directly connected to progression in teaching careers. The major impediment is that teachers are not allowed to take the courses in their working hours.

According to TALIS 2013 many Portuguese teachers have never participated in activities such as co-teaching or peer-observation. Currently only few cost-free opportunities exist in Portugal for ongoing professional development and even fewer opportunities to attend courses within school hours (Liebowitz, González, Hooge, & Lima, 2018).

The National Academy of Science in the US published an important document (NAS, 2015) on the status of preparation of science teachers to deliver the Next Generation Standards[8]. The document presents a series of conclusions and recommendations that can easily be adapted/adopted by several countries, including Portugal. Science teachers need to develop expertise in supporting a diverse range of students, improve and keep their content knowledge updated and understanding of how it relates to other subject domains, and know different pedagogical models to support the development of the scientific skills of their students. In line with some of the results and ideas I present in this thesis, the participation of teachers in professional development opportunities needs to be active and engaging. Training

[8] https://www.nextgenscience.org/

opportunities need to have sufficient duration to allow for practice and reflection on what has been learned. Teachers are also influenced by the environment in which they are teaching. The schools and classrooms in which teachers work shape what and how they learn. In NUCLIO's[9] experience, whenever we empower teachers and give them the opportunity to innovate and have ideas on new ways of delivering content, they show tremendous creativity and motivation. NUCLIO, the institution I lead, is a non-profit organization and an NGO for development where we pioneer the development of pilots for these new teaching methodologies. This shows how the support from school boards; education authorities and local communities is crucial - something also highlighted in my research in the framework of the Go-Lab project. The report suggests that training has to take place during the workday and that the content of the training has to be relevant to the teacher's subject and audience, and include opportunities to practice new teaching methods. The training should also offer collaboration opportunities, with a few examples presented in this thesis, such as the model proposed in Chapter 6. Teachers should have the possibility to count on the support of science experts and discover how STEM opportunities are emerging in the labour market by being able to visit and spend some time in different business establishments. The use of diverse media to facilitate learning is also suggested.

In a Eurydice report on Education and Training (EC, 2015a), particularly related to the teaching profession in Europe, we find that a high proportion of teachers in all age groups, irrespective of their experience and school subjects, have expressed a moderate to high level of training needs which they deem to be important in order to be able to promote a more diversified and innovative teaching practice. Professional development reaches a higher number of teachers in countries where it is considered a professional duty or necessity for promotion. As will be mentioned several times in this document, not everyone can/should be a teacher. Any professional that refuses to be a lifelong learner, in particular in fields such as education and with the digital revolution that is taking place in our days, should really consider the reasons for being a professional in that particular area. The lack of professional development of a teacher is taking away an important learning opportunity from the individual but, above all, is taking away the opportunity of students to be properly motivated and prepared without extra, and perhaps unnecessary, effort.

In Europe over 27% of teachers had the opportunity to go abroad for professional purposes ((EC, 2015a). This opportunity is necessary to enrich their vision and skill set, and to bring a whole new cultural aspect to the experience of students. The lifelong learning programmes funded by the EU are powerful means to facilitate training and introduction of innovative ideas in teachers' expertise. Some training opportunities also emerge from framework projects such as FP6, FP7, H2020, etc. Various examples will be presented in this thesis. Inquiry based learning for instance, after (Rocard, 2007) gained a lot of visibility and funding and numerous opportunities for teachers to receive training on its integration in their classes appeared all over Europe. In Portugal, according to EC, 2015a), teachers from all grade levels expressed the need for training, not the common trend in Europe. The training needs focus more specifically on teaching in multicultural environments, possibly due to the existence of large migrant communities in the country. The report also refers that CPD in Portugal cover fewer topics but provide more training days as compared to the other countries.

But training is not enough, even when conducted in culturally rich European settings. There is a need for strong and constant support. Within this document several examples will be shared, starting from the attempts to introduce into the classroom science research as done by

[9] NUCLIO – Núcleo Interativo de Astronomia – a non-profit and NGO for development created in 2001 by a group of astrophysicists. I am currently the president of the executive council of the association.

professional astronomers, using tools and data that mimic discoveries currently taking place (Pennypacker, 2006), to models designed to integrate such discoveries into the framework of the curricula. As will be presented in chapter 1, the introduction of science research in the classroom is not new - it has been conducted for over 25 years in the framework of projects like "Hands-on Universe". What is new is the globalization of the support scheme designed for such experiments which led to the founding of the Galileo Teacher Training Program in 2009, a programme, coordinated by NUCLIO, that reached over 100 nations and more than 50,000 teachers (around 1,500 in Portugal) at a global level in a very sustainable way with a long lasting legacy.

Training events need to:

- Introduce community building components (chapter 6),
- Introduce innovative ways to deliver content - for instance the flipped classroom (Bishop, 2013),
- be a model that supports the transition to a more student-centred approach even in systems with little curriculum flexibility or very constrained time schedules,
- introduce ICT in a user-friendly manner as a tool to reach the goal of the training, as a facilitator of learning,
- contextualize and appropriate the content for the audience participating in the training,
- establish the comfort zone of the participants as an initial starting point,
- include tools and resources that are made freely available (EC, 2013) and, whenever possible, in an editable format. This was the model adopted by the project Open Discovery Space (presented in chapter 1) and is mentioned in (EC, 2013) as a best practice for OER (Open Education Resources).

These training events have to be carefully designed in order to give teachers both the knowledge of how to use interactive and student-centred methodologies as well as the confidence to do it independently in their classrooms. These details will be presented in more detail in chapter 1 and further explored and enriched in chapter 6 .

In (Sotiriou et al, 2016) a series of interesting studies is presented revealing how the best educational systems promote peer to peer training as a means of professional development of educators. Studies like the McKinsey Reports (Barber & Mourshed, 2007) (Mona Mourshed, Chijioke, & Barbe, 2010) present the importance of peer to peer learning and how this improves educational systems. The best performing countries have a collaborative approach and the culture of CPD is deeply rooted in the educational system. The importance of existing peer to peer support appears clearly in the TALIS report (OECD, 2014) were 37% of teachers are identified as being involved in networks devoted to professional development. In (Vincent-Lancrin, Urgel, Kar, & Jacotin, 2019) we also find a strong reference on the importance on peer to peer learning. In my research this is also the model advocated to ensure sustainability of training initiatives, training ambassadors that will then train their colleagues.

1.5. Modern Schools - Methodologies and Classroom Design

New challenges, new jobs and new opportunities require new ways of thinking about education. Teacher-centred expository teaching in old fashioned classrooms with students sitting with their backs to each other and where no technology is allowed, is no longer in line with what is required when preparing students for their future. New opportunities are available, and we need to make the most out of them.

Considering the challenges in preparing a skilful generation of decision makers, and workers of taskforces in new emerging business models, one can foresee the road ahead. It will require a new model of preparing teachers, a new format of schools where learners have the opportunity to rehearse and engage in a set of different potential scenarios in preparation for an as yet unknown future.

Students use digital tools as a continuation of their fingers but frequently without any proper criteria related to the quality of information they are receiving, the safety of their actions or considerations to their privacy. Content knowledge is a click away but how to make proper use of it is with the skilful facilitators of learning. When entering school this innate curiosity gains a new perspective - an opportunity to enrich the opportunities presented to them is at hand. The possibility to collaborate with their colleagues enlarges an individual's horizons.

Usually, when entering school, unless otherwise already influenced to act differently, gender issues and cultural discrimination are not immediately obvious. Schools should be vigilant and alert to this problem. In (Robinson, 2005) a strong warning is presented to the role schools might have in killing creativity. In fact, while listening to this brilliant presentation one can only wonder about things we take for granted. In the face of innovation, it is only natural that schools need to incorporate new knowledge as quickly as possible and work to provide new competence requirements. Schools, however, often mimic a space mission, where everything needs to be tested and retested before being launched into space. In space exploration there is no other option, there is no room for flexibility. If a piece of equipment fails that might be it for the mission. But that is not the case for schools. Our brain has enough plasticity to accommodate trial and error. In fact, this might be the way to advance more quickly and ensure that new generations are prepared to face adversities and uncertainties when dealing with cutting edge novelties.

It is puzzling that after decades of amazing progress in so many fields schools remain doing what they did in the past, pretty much in the same vain, as if orchestrated and prepared for the industrial revolution of the 19th century. In (Robinson, 2006) severe criticism is presented against standardized tests and the way we judge people according to a criterion that tries to normalize what can't be normalized. The school classroom design is not fostering key skills such as the capability of collaborating with others, the capacity to solve problems by cooperating with others, self-regulation and the ability to independently design one's own learning path according to preferred topics or means to better understand them. The ability to accommodate a student-centred learning approach is something innate. Babies are natural inquirers; they learn continuously by making hypothesis and testing them immediately without any fear of failure. Their motivation and interest in the world surrounding them may endure as long as there is stimulation and the right incentive for exploration. The learning method has to be designed according to the individual. Teachers need to be prepared to be the beacons showing the road ahead whilst providing enough freedom for the choice of the path ahead.

Competence-oriented learning is the model advocated in (EC, 2018c) as a model that helps educators move away from knowledge-focused teaching to a model where learners take ownership of their learning and have to develop skills accordingly. A series of models are suggested integrating student-centred models such as: Inquiry Based Learning (IBL) and Project Based Learning (PBL), amongst others. The importance of multi-interdisciplinary experiences is also strongly highlighted. The use of digital technology to facilitate learning is advocated in the document as an enabler of models such as the flipped classroom, blended learning, etc.

1.5.1. Inquiry Based Learning

There are several student-centred models, and each have different characteristics and should be used in different circumstances with different students. The roots of Inquiry Based Learning (IBL) can be found in the work of John Dewey (Dewey, 1910), Vygotsky in 1939 (Vygotsky, 1986), (Piaget, 1929) among others. One of the most popular implementation of the methodology is known as the 5Es Model (Bybee et al., 2006): Engagement, Exploration, Explanation, Elaboration and Evaluation. Inquiry can be applied in several subject domains such as history, geography, the arts, as well as science, mathematics, technology and engineering - whenever questions are raised, evidence is gathered and possible explanations are considered. (Harlen, 2013). Students can be introduced to the process in a structured way where teachers and learners have complete control over the whole process and slowly brought to a more open inquiry where the degrees of freedom allow for an independent process of knowledge acquisition.

This thesis focuses on the inquiry-based learning (IBL) methodology. IBL was advocated by (Rocard, 2007) alongside a series of innovative measures to reverse the decreasing interest of students in STEM subjects. This methodology will be further discussed in chapter 7. In a nutshell it is a methodology that intends to engage students in an authentic scientific discovery experience by encouraging them to ask questions in order to get information, instead of passively listening (Pedaste et al., 2015). The definition that highly influenced the descriptions and research on IBL was proposed by the National Research Council (USA): “Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (Loucks-Horsley & Olson, 2000).

In recent years a major revision of standards in the USA proposed a broader definition of IBL, clarifying that students involved in this methodology can only understand scientific practices or appreciate scientific knowledge if they have some practical experience (Quinn, 2012). In this new definition the authors clarify that the reference - "practical experience" - implies not only the acquisition of competences but also knowledge about the specific theme. Incidentally, this has been a recurrent criticism of the inquiry methodology in its most open form in which sometimes no prior knowledge about the subject is required. Such an open approach is not entirely in accordance with what scientists do - that before making hypotheses or drawing their experiences, indeed they must acquire a deep knowledge on the subject to be explored.

However, IBL requires a way of acting in the classroom, by the teacher and students, which is not in line with current teaching systems that are strongly targeted towards university entrance. Students are subject to exams that mostly test knowledge and not competences. It requires teachers to navigate a dense curriculum, leaving little room for exploring the far-reaching world of Inquiry (Bybee, 2010).

In (Pedaste et al., 2015) a comparison of different models is presented: The comparison focuses mainly on two points: 1) Which inquiry phases are necessary for a complete inquiry-based learning approach? 2) How should the inquiry phases be arranged? A large database of research on IBL was analysed and the most common phases identified: Orientation, Questioning, Hypothesis Generation, Planning, Observation, Investigation, Analysis, Conclusion, Discussion, Communication, and Reflection. These were then merged and reorganized in the framework that is being followed by the Go-Lab project. The Go-Lab inquiry cycle has 5 distinctive phases as described in the diagram below (figure 3):

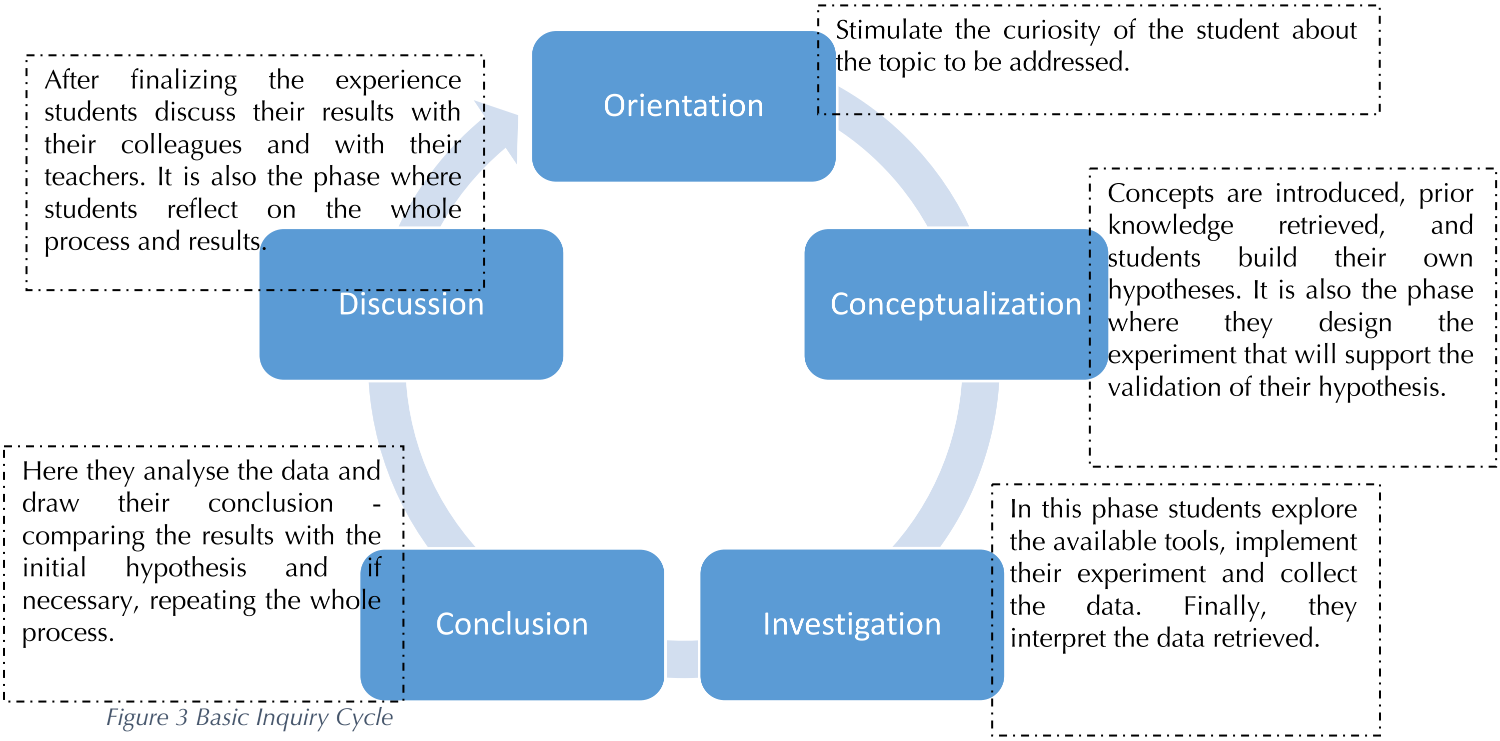


Figure 3 Basic Inquiry Cycle

There are several different models of inquiry, with different levels of structure and phases. The value they should bring to the students' education is well summarized by (Harlen, 2013).

Through their science education students should develop:

- understanding of fundamental scientific ideas
- understanding of the nature of science, scientific inquiry and reasoning
- scientific competences of gathering and using evidence
- scientific attitudes both within science and towards science
- skills that support learning throughout life
- ability to communicate using appropriate language and representations, including written, oral and mathematical language
- appreciation of the contribution of science to society and of how science is used in technology and engineering.

(Harlen, 2013) presents a very concise comparison between learning through inquiry and through the transmission method (Table 1):

Table 1 Comparison between learning through inquiry and the transmission method (Harlen, 2013)

Learning through inquiry	Learning through transmission method
Students pursue questions which they have identified as their own even if introduced by the teacher	Students' activities follow a sequence set out in a text-book or by the teacher with little attention to placing what they do in the context of a question they want to answer
They do not know the answer to the questions they investigate	They may read about how to conduct investigations but have little opportunity to experience the process for themselves.
They know enough about the topic to engage with the question	They may observe demonstrations by the teachers but may not understand the reasons for what is being done
They make predictions based on their emerging ideas about the topic	When they do undertake practice activities they follow instructions taking little part in deciding what to do
They take part in planning investigations to test their predictions	The experiments they observe or conduct are designed to confirm a conclusion already known: 'experiment to show that ...'
They conduct investigations themselves	They do not always know why certain steps in an experiment or investigation have to be carried out
They use appropriate sources and methods of collecting data relevant to testing their predictions	They write accounts of investigations in a structured form, often copied from a book or dictated by the teacher
They discuss what they find in relation to their initial expectations or predictions	They record the 'right answer' even if they did not observe what ought to have happened

A good definition of inquiry is not enough (Dutton et al., 2013), it is necessary that the teachers feel confident to implement the model and that they have the necessary training for its proper implementation. A deep understanding of the concept, and experience in transforming the traditional expository lesson to a model that puts in the hands of the student the responsibility for the learning are both paramount. These components are deeply explored in my research. The lack of experience and confidence by the teacher are not the only barrier to good implementation of inquiry in the classroom. Teachers also face very dense curricula, lack of time to integrate the methodology in school hours, the need for a lot of preparation, the risk of the experience not being successful, etc. (Bogner, Schmid, & Dieser, 2013). (Bybee, 2010) provide an interesting study that shows how tasks in the world of work have changed from the 1960s to the present day. Mechanical work, which can be easily described by logical and sequential rules, is being replaced by computers. What is necessary now are professionals with communication skills, critical thinking, problem-solving ability, creativity, among other important competencies, who use machines capable of following logical and sequential rules, computers, as a source of information and inspiration. Advanced figures for the United States of America are alarming, it is predicted that 50% of students can end their academic life without acquiring the skills necessary to tap their full potential. This is identified as the primary

concern of politicians around the world: to provide citizens with the skills they need to reach their full potential and to participate actively in the global economy (OECD, 2013).
An excellent table presented by (Bybee, 2010) correlates the valued competences for the world of work with characteristic of learning by inquiry (science classrooms in this case) (Figure 4).

Developing 21st-Century Skills in Science Programs

Essential Features of 21st-Century Skills	Examples of Contexts for School Science Programs
Adaptability	
• Cope with changing conditions	• Work on different investigations and experiments
• Learn new techniques and procedures	• Work on investigations or experiments
• Adapt to different personalities and communication styles	• Work cooperatively in groups
• Adapt to different working environments	• Work on investigations in the laboratory and outdoors
Complex Communications/Social Skills	
• Process and interpret verbal/nonverbal information	• Prepare oral and written reports communicating procedures, evidence, and explanations of investigations and experiments
• Select key pieces of complex ideas to communicate	• Use evidence gained in investigations as a basis for a scientific explanation
• Build shared understanding	• Prepare a scientific argument
• Negotiate positive outcomes	• Work with group members to prepare a report
Nonroutine Problem Solving	
• Use expert thinking in problem solving	• Recognize the need to search for expert's knowledge
• Recognize patterns	• Recognize patterns in data
• Link information • Integrate information	• Connect evidence and information from an investigation with scientific knowledge from textbooks, the web, or other sources
• Reflect on adequacy of solutions	• Understand constraints in proposed solutions
• Maintain several possible solutions • Propose new strategies	• Propose several possible solutions and strategies to attain the solutions
• Generate innovative solutions	• Propose creative solutions
Self-Management/Self-Development	
• Work remotely (individually)	• Work individually at home
• Work in virtual teams	• Work with a virtual group
• Self-motivate	• Complete a full/open investigation
• Self-monitor	• Reflect on adequacy of progress, solutions, explanations
• Have willingness and ability to acquire new information and skills	• Acquire new information and skills in the process of problem solving and working on investigation
Systems Thinking	
• Understand the systems concept	• Describe components of a system based on a system under investigation
• Understand how changes in one part of the system affects the system	• Predict changes in an investigation
• Adapt a "big picture" perspective	• Analyze a system under investigation
• Systems analysis • Judgment and decision making	• Make decisions about best proposed solutions
• Abstract reasoning about interactions among components of a system	• Demonstrate understanding about components and functions of a proposed system

Figure 4 Developing 21st century skills through science learning (Adapted from Bybee, 2010) .

The next challenge that appears when one shifts the methodology to IBL is how to assess the students. The simplest and most used format is undoubtedly the test of the ability to memorize and reproduce skills. The preparation of students for a good performance in this typology of evaluation is also simpler. But this form of teaching leads to deep gaps in the training of apprentices. A successful student in this typology of assessment will not necessarily be a well-prepared student for a 21st century job. When shifting to a more student-centred approach, assessment has to assume a completely different format. A strong formative component needs to be in place, teachers should be properly prepared for its current use. Prior criteria can be established and used to follow the development process. The evaluation can take the form of a debate, it can be an integral part of a debate between students, a presentation and / or discussion of results. It can also integrate self-assessment by learners. The assessment should be used to help students while they are learning and to find out what they have learned so far (Harlen, 2013). The formative assessment (Figure 5) should be implemented across the learning experience and should be a flexible and adaptable process. The student has to be an active participant in the process.

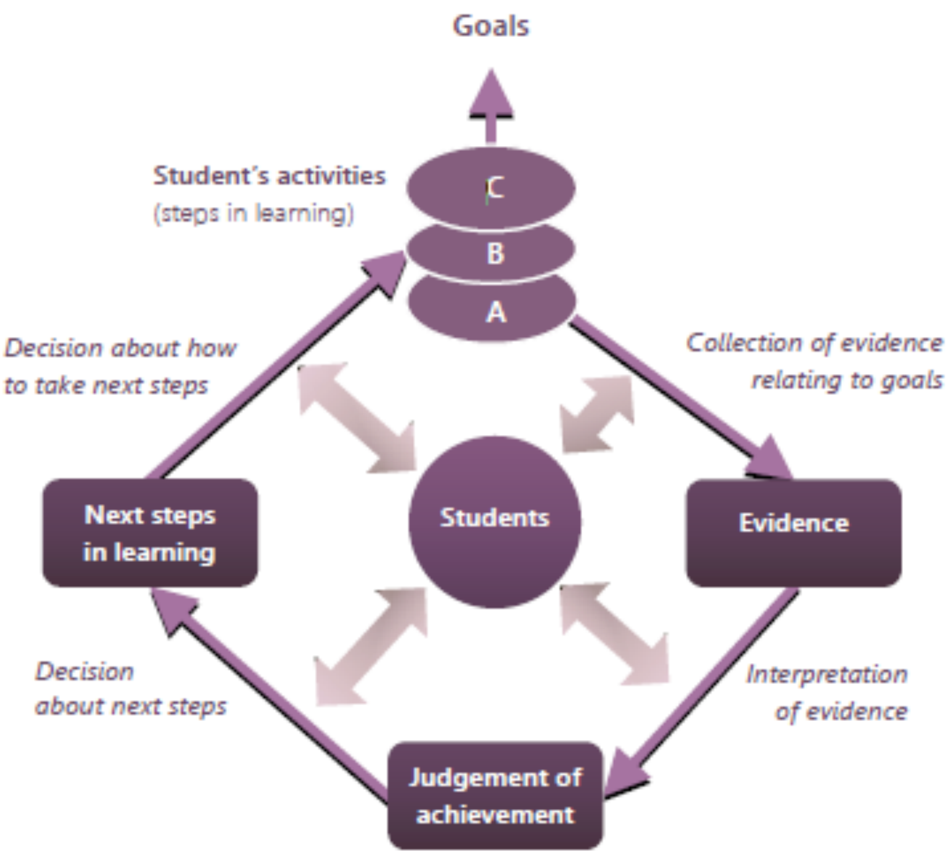


Figure 5 Proposal of a formative assessment (Harlen, 2013)

The summative assessment (Figure 6) should be seen as promoting an overview of student learning. This component can be constructed from the collection of evidence, for example from moments of formative actions, allowing to evaluate the scope of the objectives initially proposed.

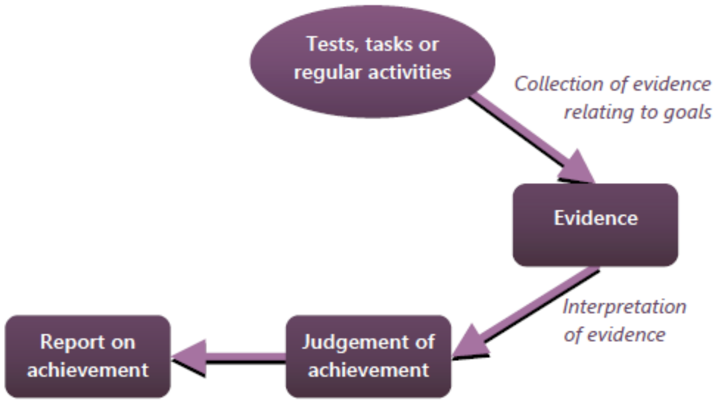


Figure 6 Proposal of a summative assessment (Harlen, 2013)

Implementing a proper assessment scheme is easier said than done, in particular when students are chasing the optimal results in exams that will eventually open the doors to the so expected University entry. In chapter 7 a presentation of a possible means of assessing IBL is presented. The model was used and validated in the framework of the PLATON project.

1.5.2. Technology Enhanced Learning (TEL) and ICT in schools

According to (de Jong, 2016) computer simulations enhance IBL. In the article it is argued that the integration of supportive cognitive tools of computer simulations helps solving the typical impediments students find when being exposed to IBL. Jong suggests that students should learn how to regulate their own learning, how to gain and improve knowledge. When used for science learning IBL serves as a mechanism to involve students in authentic discoveries by using a scientific approach and making their own discoveries. The use of virtual simulations to model an experiment, where students can change variables, observe the result of their choices and repeat the experience many times, may help the student understand the involved phenomena.

In (de Jong, 2016) a list of typical problems faced by students when exposed to this methodology is discussed, such as: choosing the right variables, state their hypothesis (sometimes even understanding what a hypothesis is). One may also add their difficulty in manipulating one variable at a time, their fear of making a mistake, the constant search for a place that provides the right answer (like the answer at the back of the book). Students often fail to properly interpret the data being retrieved and often try to manipulate variables to reach the result they were initially expecting. The Go-Lab project integrates a series of apps that can act as support to facilitate the work of the student. The environment allows educators to seamlessly integrate the necessary background information, to provide in time individual feedback and to tailor the learning environment to the needs of the students. Virtual labs can be used in one or several phases of the process and act as steps towards the understanding of the phenomena being studied by the student.

Technological advancements can greatly increase the success of a methodology as presented in (de Jong, Sotiriou, & Gillet, 2014) and that is the proposed model used in the Go-Lab project presented in more detail in Chapter 6. The first step was to create in schools favourable conditions for its use. There are several factors that have to come together for this to be a reality in students' experiences. (Deloitte, 2018) shows (or argues) that internet connectivity in schools is still far from what is necessary for students to take proper advantage of it. More than half of the students (at a European level) use a computer at school at least once a week, in

Portugal this number goes down to 36%. Smartphones are the most used own device in schools, in Portugal this use reaches 40% of the students. This number has not changed much since 2011-2012. Most teachers use ICT in more than 25% of lessons but the mode of use needs to be clarified. Usually teachers prepare the lessons, make summaries of the lesson content and frequently present videos and slide show presentations. This is not equivalent to the use of technology as a means to enhance learning. When it comes to professional development, less than 30% of teachers have compulsory participation in ICT training. This is also reflected in the statement that teachers feel least confident in creating digital content than using it for communication and other less demanding tasks. Most students at European Union level have some form of access to digital content at home. Close to 100% have access to computers. In Portugal close to 80% of students have access to smartphones and 70% to tablets. Teachers consider that schools don't have necessary equipment and that there is lack of (technical and pedagogical) support.

Many countries are still a long way from transforming mainstream education into a space and place where the knowledge and skills needed for the 21st century are at the core of everyday classrooms. New approaches to teaching and learning are necessary with the integration of innovative pedagogies. The solution to achieve this goal is, of course, in the hands of teachers. (Paniagua & Istance, 2018) provide a series of examples on how this important task can be achieved. A series of key messages are presented in the report: innovating in the classroom is not something that a few talented teachers can do, instead it requires a complete restructuring of the formation of teachers. Students must be treated as individuals and innovation should match their specific characteristics, students-centred focus requires time investment, there is no shortcut, teachers need to have school support, teachers need to acquire the necessary experience and skills to be able to integrate innovative pedagogies in their practice. The separation between subject domains must be removed, new assessment models need to be in place to accommodate these innovative pedagogies.

1.5.3. Designing 21st century learning environment

The best classroom in the world is the one where students feel comfortable, one that feels like a continuation of their homes. In Portugal several modern learning environments are emerging - the Future Classroom Labs - there are more than 34 spread across the country. These are cutting edge facilities, well equipped and tailored to provide all kinds of opportunities for the integration of ICT tools and resources to facilitate student learning. They are spaces divided in different zones, each devoted to a specific action (Baeta & Pedro, 2017): Investigate, Create, Exchange, Develop, Interact and Present. This is just an example of organization of such a space (Figure 7).

Figure 7 Presentation of the concept of a FCL (EUN - European Network of Schools)

In these spaces technology and methodology are combined to provide students with the optimal conditions for learning. However, these spaces often require a substantial financial investment, not accessible to all schools. What makes these spaces unique is not the equipment that they host but the model they adopt. A model that promotes collaboration between students, a place where they feel at home. In several of the spaces popping up across the country it is becoming clear that teachers in Portugal are not yet prepared to take advantage of the features of such spaces. Other examples of inviting environments are possible without the need for a lot of investment. In Figure 8 we see a series of examples of such initiatives implemented with the support of teachers and parents. All that is necessary is a shift from the normal classroom environment where students are all seated facing in one direction, not facing each other and the teacher is taking centre stage. Students need a space that sparks their creativity and gives them a feeling of freedom.

Figure 8 Top: a space for students to take their physics classes in the school garden (Funchal - Madeira). Bottom: an English Classroom; a piano classroom; reproduction of the Altamira Caves in a school in Gijon) © NUCLIO

Examples like this are not new to Portugal. In the iconic "Escola da Ponte" there is a very innovative model of teaching that doesn't have classrooms or grade levels. It organizes itself around the concept of autonomy of the students and independent learning with teachers working as facilitators of the whole process. The school has implemented this model since 1976 and became an example known worldwide. The school inspires other examples around the world. In Brazil for instance a whole new movement is emerging, following the steps of this school (Singer, 2016)

In summary, the school environment should be inviting to learning. Teachers should be open to integrate new models of teaching/learning and should have the opportunity to prepare the environment in order to meet their views for the learning that is about to happen. It should incorporate design thinking strategies (a model used by companies to adapt their product to their target audience) so the setting will be adapted to the specific needs and characteristics of the learners. Online opportunities for learning should be incorporated in the experience of the students making the most out of the possibilities that digital tools can provide. In countries such as Portugal there should be no digital or cognitive divide preventing students from reaching their maximum potential.

1.6. Education and the sustainable development of our planet

When we consider what is necessary for a successful future of students, we have to take into account that we also must consider what the future holds for them. We are the tutors of the future generation; they are the ones that will receive our legacy as leaders of this world. Our generation is facing severe problems that put in danger the sustainable development of our species. It is fair to say that perhaps the most important knowledge to be shared is the existing goals for sustainable development, the SDG (Sustainable Development Goals) (Figure 9) and the reason for their existence. Along with this awareness students need to be equipped with the necessary competences to handle and maybe mitigate these problems. The fact we face them in the 21st century is a pretty embarrassing reality for humanity (UN, 2015).

Figure 9 United Nations Sustainable Development Goals for the Millennium

According to (Unesco, 2015) the importance of a humanistic and holistic approach to education is reinforced as the only way forward. There is no future without the realization that we are humans living on a planet that doesn't show borders when seen from space. A rich and friendly place for humans, the only place we can live and probably the only one for many years to come (Sagan, 1994). Globalization of education is also emerging and there is no turning back. Digital tools, emerging trends for knowledge sharing and content delivery are opening the doors to anyone with a smart device with an internet connection. Thus, education must receive an upgrade as Education 2.0 is here to stay. Education should be personal, collaborative, relevant, multimodal, technical and open-minded among other important adjectives (YDP, 2015).

The world's possibilities are constantly acquiring a new meaning and new limits. Jargon such as Artificial Intelligence, Neuronal networks, etc. are invading our lives. Climate change and renewable energies are now topics of everyday conversations. Refugee crises and extremism being reborn. All of this should be at the heart of the roadmap redefining the meaning of the pillars of education as described by UNESCO (Delors, 1996). In Portugal these challenges and new frontiers are integrated in the National Strategy for Education and Citizenship (DGE, 2017). Rethinking citizenship education in a diverse and interconnected world is a high priority (Unesco, 2015). Schools have to be open hubs for their communities and accommodate the challenges and opportunities existing within. Cultural diversity should be used for the benefit of all, retired members of local communities should contribute with their knowledge to enrich the learning experience of students and the latter should be a beacon, a referrence, to those in need.

1.7. The School Curricula

One of the key factors that limits the implementation of innovative formats for teaching is the very prescriptive and very dense curriculum. The most commonly found factor among the barriers listed by teachers is that it is not possible to allocate sufficient time in the classroom for inquiry experiments (Harlen, 2010). Another relevant issue is how the transmission of knowledge is departmentalized and often decontextualized. Very often we find identical concepts in different disciplines being transmitted completely differently by different teachers. This is not necessarily a bad thing, but sometimes the content becomes contradictory and it is not always clear to students what fundamental concept is being conveyed and how things relate. Understanding the great ideas of science needs more than knowledge of historical names and facts. A contextualized and related thought was presented by (Harlen & Bell, 2010) which lists 10 great ideas of science and 4 great ideas about science. Innovative projects built on these ideas are now being implemented in the European Union and promising results are expected. Some of these projects are a fundamental part of this thesis (Go-lab, Inspiring Science Education and PLATON). The research presented here uses the tools provided by these projects. According to (OECD, 2014) the schools that show the best results are those that guarantee greater autonomy in both the curriculum and in the evaluation of results.

In order to encompass all the necessary changes, the curriculum, needs to assume a lighter and more flexible role. The Education 2030 position paper (OECD, 2018d) identified a series of common challenges related to the curricula, such as information overload, gaps between identifying the need and the actual lack of equity, low quality content among other issues. As an initial attempt to overcome these problems, a series of design principles were presented: Curricula should be motivational; should enable deep thinking and reflective; have a small number of topics to ensure the depth and quality of student's learning. It should be presented in a coherent manner, well aligned with assessment practices and give high priority to skills, attitudes and values that can be transferable in nature. Content knowledge is certainly a building block of our literacy in all fields but simply accumulating it without the knowledge of how, when, why and where to apply it is useless (OECD, 2018e). Having the appropriate skills but a lack of content knowledge is also not beneficial. The virtue, as in everything in life, is in the middle.

According to (OECD, 2018a) the Essential Core Curricula Initiative, launched in Portugal in order to overcome the overcrowded curricula issue legitimised some pedagogies that have been sporadically used in normal classes, as well as in extracurricular activities. The project encouraged teachers to take part in the design and implementation of a more diverse and rich curricula. It opened the door for active engagement of members of the school and local communities. There is now room for interdisciplinary, cross-classroom and cross-grade activities and finally ICT now has the room to be easily integrated in many different subjects. The document outlined the following strengths:

- The involvement of several stakeholders in the construction of the student's profile which enabled them to understand the broader educational vision outlined by the proposed profile,
- It gives legal space to schools to explore various possibilities for progressive curriculum design,
- The initiative has the potential to increase inclusion and equity in Portuguese schools,
- It enabled students to experience and value effective elements of curriculum design such as: learn how to work and learn together with peers (in horizontal and vertical articulation); build positive relationships with teachers; make choices that reflects their interests; present their work outside the classroom; learn things that are relevant to their

future; connect with professionals in the community; experience a diverse range of learning methods.

It also identified a series of challenges faced by teachers while trying to implement the new model:

1. Teaching for the national exam versus promoting active learning, formative assessment and other pedagogies,
2. New curriculum designs might lead to complexities in finding different ways to structure school time, with different degrees of effectiveness,
3. Enabling teachers and students to exercise autonomy and flexibility in designing curricula takes time and sustained commitment.

The OECD conducted a review of school resources in Portugal and assessed among other things the results of the changes implemented so far (Liebowitz et al., 2018). In the report it is mentioned that despite the fact that there is now greater curricular autonomy there are still constraints imposed by the national curriculum on innovative teaching practices.

1.8. Changing Education – The Portuguese Example

In September 2017 Portugal launched (DGE, 2017) a national strategic plan of education for citizenship. Associated to it several actions were implemented "Autonomy and Curricula Flexibility" (Martins et al, 2017a), the "Profile of the Students at the End of Compulsory Education" and the Core Curriculum Competencies/Essential Learning (Martins et al, 2017a). With these changes, schools were given the freedom to use 25% of their teaching hours for the integration of a collaborative, interdisciplinary project-based learning area - the so-called DAC (*Domínios de Autonomia Curricular* – Domain of Curricular Autonomy). The Education and Training Monitor highlighted these changes stating that the principles, values and areas of competence covered aim to support the education and development of active citizens (EC, 2018a). The same report presents encouraging numbers showing that the number of early leavers is continuously decreasing since 2008, reaching a country average of 10% (as compared to over 30% in 2008). The ageing teacher population is referred to as a potential challenge. The majority of Portuguese teachers are in their late 40s and only 1% of teachers are under 30. In 2015 access to the teaching career presented a huge challenge to those willing to pursue this path, according to (EC, 2018d) the ratio in the national competition for temporary (annual) vacancies was 1:7. This is a relevant indicator and has implications when the goal is to shift the model in schools to a more innovative and ICT based learning experience. The younger the teachers the easier it is to introduce TEL (Chapter 6) and the easier it is to shift from expository teaching to a more student-centred model. The strategy for recruitment of new teachers is also lacking an important component - testing the competence profiles of teachers to handle the desired innovation for education. It is not their existing competences in ICT, new methodologies, etc., it is their openness to accommodate an inclusive approach to education in their classroom strategies, and willingness to engage in promoting 21st century skills.

The National Strategy of Education for Citizenship (Estratégia Nacional de Educação para a Cidadania) presents a set of rights and duties that should be part of the education of Portuguese students in order to raise individuals with a civic conduct that favours equality in interpersonal relations, respect for human rights and the values of democratic citizenship (DGE, 2017). The document advises schools to integrate a list of recommendations in their daily practices that promote values and principles of citizenship, to promote an open and free environment inclusive of all members of the community. It suggests both the involvement of the community as a whole and the engagement of external stakeholders in order to enrich the school network. The recently created DAC should focus on the needs and existing resources of each community and as such incorporate real situations to apply active citizenship. The document highlights components of the profile of teachers involved in new learning spaces. Among them: to know how to create learning scenarios that foster the development of critical thinking, collaborative and problem-solving competencies; be capable of fostering learning situations in collaboration with the community; to know how to promote project-based activities; master the use of ICT tools; and be motivated to perform the task. In order to materialize this strategy, as mentioned above, another important document was created: the "Profile of the Students at the End of Compulsory Education" (Martins et al., 2017). It aims to create a reference framework the encompasses freedom of choices, responsibility, recognition of work, self-awareness, family and community insertion and participation in the society that surrounds us. The above profile has in its essence a very humanistic view of education, key to promote learning for citizenship and sustainable development. The profile is underpinned in a series of principles, translated in a set of competence areas and values (Figure 10).

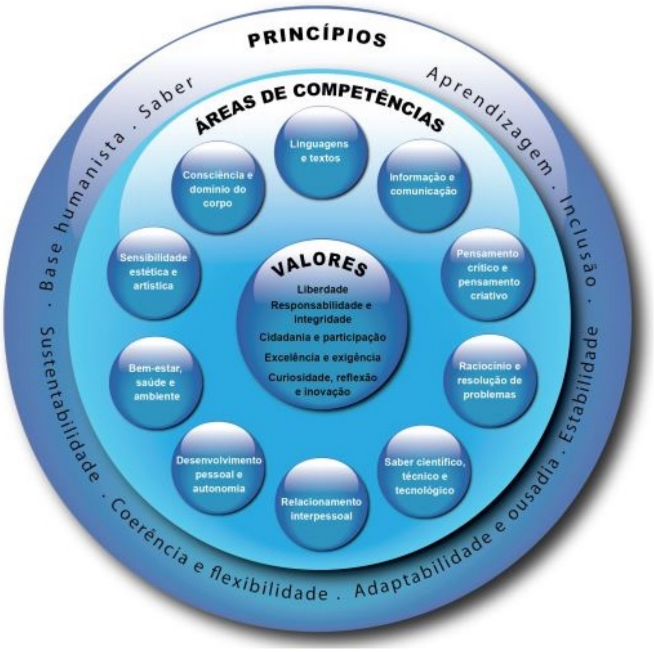


Figure 10 Principles, competencies and values of student profiles when leaving compulsory school. Adapted from (Martins et al., 2017)

Among other envisaged results, the vision of this profile encompasses that students will leave school with multiple literacies that enable them to analyse and critically question; assess and select information; formulate hypotheses; make informed decisions; collaborate and communicate; and, finally, find creative solutions to problems. The acquired competences follow the structure presented in Figure 2. Each competence and its importance are detailed in the document as well as the need for the specific outlined values. It is a very complete but flexible document that paves the way for innovation in schools based on a strong competence profile.

Alongside other documents the government also released the Essential Core Curricula Guidelines (ECCG) as an attempt to address the curriculum overload (Martins et al., 2017a). The core curriculum is a living structure that is constantly being revised and to which tools and resources are being connected as a means to support the work of the teachers. It targets the curriculum overload trying to provide more space to the development of student competences.

Accompanying this document Portugal promoted a pilot project, now enlarged to all schools in the country, providing Autonomy and Curriculum Flexibility (Palmeirão & Alves, 2017). The project, called PACF (Project for Autonomy and Curriculum Flexibility) provides schools with the necessary conditions to manage the curriculum and integrate innovative practices to improve student learning. The OECD conducted a review of the project and produced a report with the main outcomes of their review (OECD, 2018a). The report is intended for other countries that might use such an initiative to help redesign their own learning models. It refers positively to the replacement of exams in some grades by other forms of assessment with a more formative nature and the launch of a national initiative to promote digital skills (INCoDe.2030). The document also refers to the fact that students are now surrounded by "fake news" and complex social media, are faced with increasing cultural diversity and must thrive in an evolving world. Global awareness and mindset to take responsible actions are necessary competences for today's students. In this direction, the new PISA study (OECD, 2018c) has included a test on global competences, the preparation of youth for an inclusive and sustainable world. It includes content domains, specific skills, attitudes and values. The report presents some concern on how the vision of the profile of students can be materialized but acknowledges that the PACF may be a suitable way to attain such an objective. There are of course several challenges, some of which we witnessed while implementing our projects in Portuguese schools. Humans don't like change and are frequently reluctant to step out of their comfort zone. One thing is to have a good theory, another thing is to put it into practice.

In terms of in-service teacher training courses in Portugal, in general, they are proposed either by higher education institutions or via the existing training centres network. Courses are accredited by the CCPFC (*Concelho Científico-Pedagógico da Formação Contínua* - Scientific-Pedagogical Council of Continuing Education). In-service training courses are in general concentrated on general themes and it is sometimes hard for science teachers to find suitable training for their area (Dourado, Leite, & Morgado, 2016). It is mandatory for teachers to have a certain number of general courses and a certain number of specific domains. There should be more flexibility to train teachers from different subject domains and in vertical articulation under the same training course. Teacher's learning is more robust when participants can interact and exchange both ideas and expertise. The setting needs to be inspirational for the task being presented to them (Merchant, 2004). Mixing different experiences in a collaborative environment is a powerful experience. Schools can no longer be teaching spaces with rigid structures, they have to become learning environments, beacons for their communities. Schools should seek to understand the community it serves and foster its potential while targeting its needs.

1.8.1. DSOE - Digital Schools of Europe – The Portuguese case

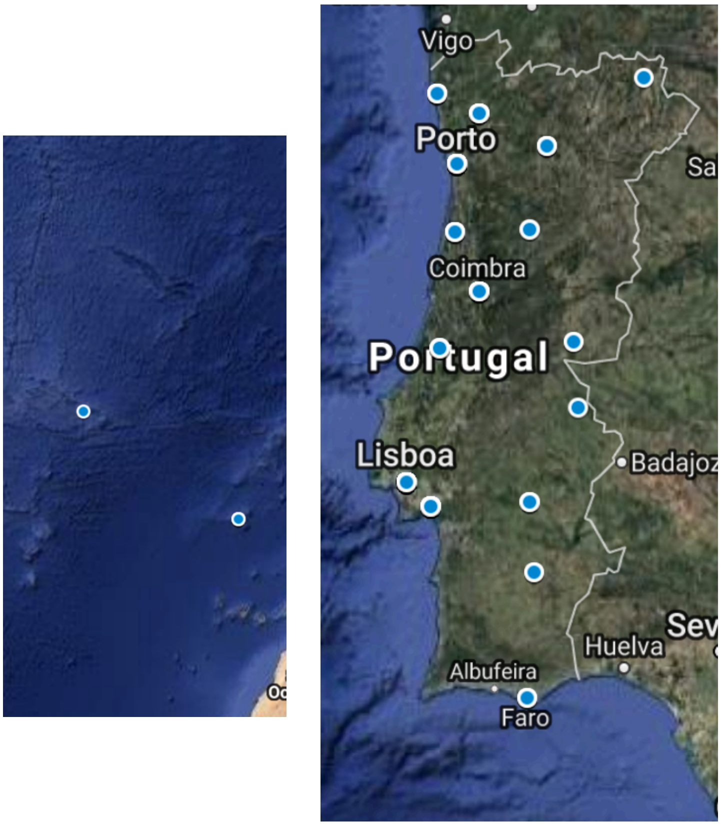


Figure 11 Distribution of Schools that took the self-evaluation test in Portugal

The Digital Schools of Europe were part of a follow up project of the Digital Schools of Distinction from Ireland[10] where schools received national recognition in the form of an Award accredited by the Department of Education. The project evaluated how technology enhanced learning is embedded in the school as a whole and provided a roadmap for schools willing to receive the recognition. The project targets only primary schools and by January 2019 over 450 schools received this award.

The main goal of DSOE was to test the DSOD model in other countries. In all the countries that participated in the project the self-evaluation tool that was used was the same to allow a harmonization of the results.

The model was adopted by the project Open Discovery Space, presented in this document, and formed the basis of SELFIE (Kampylis, Punie, & Devine, 2015).

In Portugal the project was coordinated by NUCLIO, where I took the role of national coordinator, and at the end of the project a national initiative was officially launched as *"Escolas Digitais"* (Doran, R., in prep).The goal of this project was to reach 100 national schools as well as evaluate their level of maturity of Portuguese schools on the use of

[10] http://www.digitalschools.ie/

technology for innovation in education. At present (January/2019) a total of 69 schools replied to the self-evaluation test and below we present a summary of the results. All the results are presented in Appendix I

The self-reflection form was updated to include more advanced options of ICT integration and also options for schools that are now entering the ICT realm. This work was done by me in partnership with Neil O'Sullivan from DWEC (the coordinators of DSOE)

- There was a good distribution of schools across all grade levels as can be seen in Figure 12

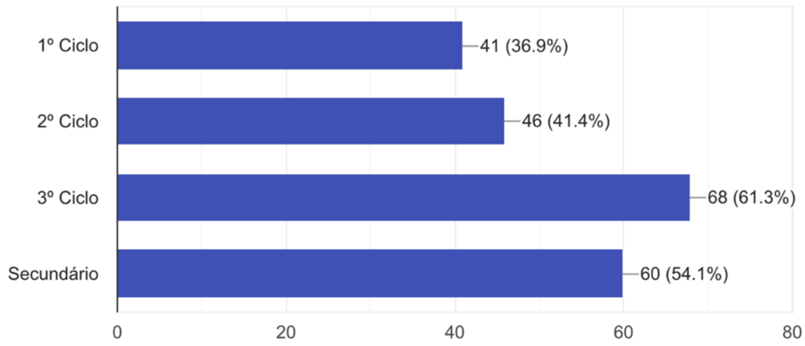


Figure 12 Distribution of schools according to grade level

There were schools coming from different places across the country with a larger number of replies coming from Lisbon district (Figure 13).

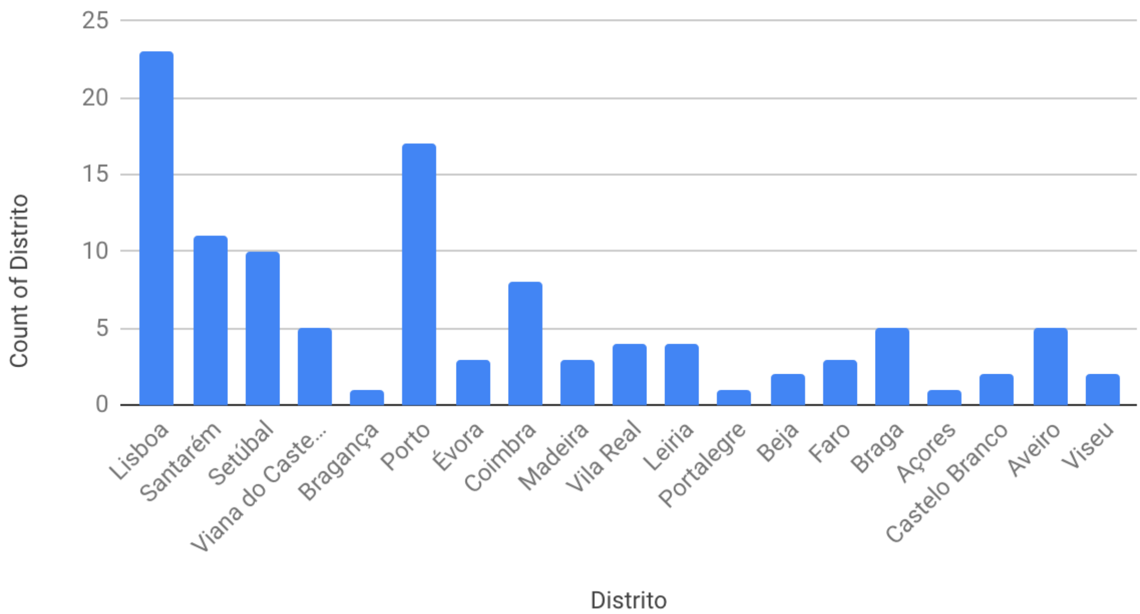


Figure 13 Distribution of replies per district

The roadmap, the supporting tool created by the Digital Schools of Europe and upgraded by Neil O'Sullivan and I has five strategic areas. Below we present first the result area by area and then finally the full result. These results represent the state of the art related to Technology Enhanced Learning (TEL) in the respondent's schools:

LEADERSHIP AND PLANNING

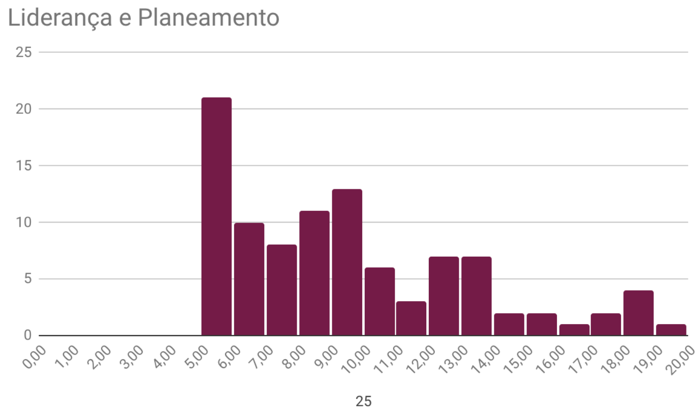


Figure 14 Results for Portuguese Schools in the Field of TEL Leadership and Planning

The maximum possible grade in this field is 20 points. The minimum to be awarded the Digital School status is 12. It is clear from the graphic (Figure 14) that unfortunately Leadership and planning are not an integral part of the strategy of the Portuguese schools. There is a lot of room for improvement.

- VISION - **40.4%** of schools are focusing mainly in ICT equipment. **29.3%** have a vision for TEL developed by a team of teachers, **18.2%** attained the confident level with the vision of TEL completely integrated in the school and **12%** reached the developed level by having a TEL vision shared by all and used to promote learning.

- PLAN- Over **48.5%** of respondents have only a basic ICT plan for the school and **32.3%** have a plan developed by a dedicated TEL team, in **11%** of schools all the teachers contribute to the plan and in **8%** of schools students are also involved

- INTEGRATION - In **37.4%** of schools the focus is mainly in acquiring basic ICT competences, in **30.3%** the focus is to integrate ICT in the whole school, **24.2%** integrates also a more overarching scheme to use TEL to improve learning, and **8%** of schools use TEL to facilitate personalized learning,

- SPECIAL EDUCATIONAL NEEDS - **51%** of schools use ICT to promote learning for students with special needs but in an uncoordinated way,

ICT IN THE CURRICULUM

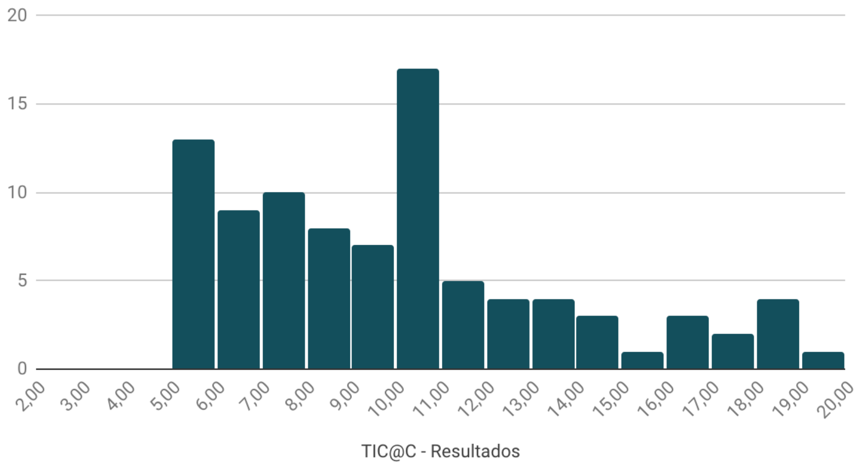


Figure 15 Results for Portuguese Schools in the Field of integration of ICT in the Curriculum

The maximum possible grade in this field is 20 points. The minimum to be awarded the Digital School status is 11. In terms of Teacher's understanding and planning the schools are average but in terms of student experience and special educational needs there is a long way to go (Figure 15).

- TEACHER UNDERSTANDING - **34.7%** of teachers have a general understanding of the use of TEL to improve learning; over **33.7%** know how to integrate ICT in the curricula; approx. **21.4%** of the teachers understand how to integrate ICT in the curricula to improve learning and **10%** choose their own methodologies to integrate ICT in the curricula,

- PLANNING - **33.7%** of schools reveal having little planning in integrating ICT in student activities and are restricted to things like word processing; in **49%** of the schools there are plans to integrate ICT in the curricula for the whole class teaching and focusing on some individual work; in **13%** of the schools, teachers plan in a structured way the integration of ICT in the curricula and only **4%** of schools devote time to explore new ways to use TEL to enhance student learning,

- TEACHER USE - **20.4**% of schools report that teachers use computers in an isolated way; **49%** of teachers use ICT to plan their lessons and as a tool for teaching; **21.4 %** use ICT to foster learning opportunities, centred on students with a constructivist base and **9.2%** incorporate ICT in their daily practice to facilitate student learning in a student-centred format and with a constructivist basis,

- STUDENT EXPERIENCE - In **44%** of schools students use ICT occasionally as part of the learning process; **33.7%** of schools report that students are exposed to TEL activities on a regular basis; **11.2%** are exposed to TEL activities and use ICT to collaborate with their colleagues in school, outside school and with other schools; in **11.2%** of the respondents school students use ICT to support and evaluate their learning, to create digital content and ePortfolios,

- SPECIAL EDUCATION NEEDS - In **48%** of schools teachers are aware that ICT can improve the learning opportunities of students with special needs; **31.6%** of teachers use ICT focusing on the development of literacy and numeracy of students with special needs; **11.2%** of teachers use ICT tools to diagnose special needs and to address curricular objectives; **9.2%** ICT is essential in all teaching and learning aspects of teaching and learning for students with special needs as well as are incorporated in all levels of the school planning.

PROFESSIONAL DEVELOPMENT

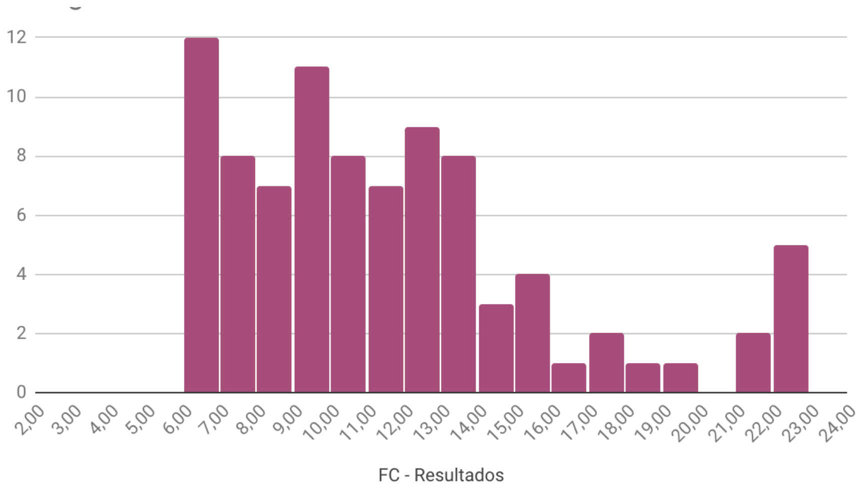


Figure 16 Results for Portuguese Schools in the Field of Professional Development

The maximum possible grade in this field is 20 points. The minimum to be awarded by the Digital School status is 14. This is a very important field and it is evident that the vast majority of replies are below the desirable threshold (Figure 16). Promoting the ICT integration for the CPD of teachers is urgent.

- TEACHER AWARENESS & PARTICIPATION - **37.9%** of schools report that only a few teachers have participated in CPD related to ICT; in **36.8%** more than half of teachers have; in **23.2%** of schools most teachers have participated in CPD opportunities; and in only **2%** of schools teachers participate in communities of practice.

- PLANNING - In **48%** of schools only a few interested teachers identify their own professional development needs; in **35%** of schools there is also a TEL team that identifies the needs of the whole school in terms of ICT; **12.8%** of schools have an ICT coordinator or a TEL team that identifies the needs and implements the CPD; **4.2%** of schools report that teachers involve themselves in self-evaluation and reflection in order to progress the school CPD programme.

- FOCUS – **32.6%** of schools reported that the focus is in the development of basic ICT skills; **48.4%** have less than half of their teachers engaged in ICT professional development; **10.6%** have most of the educators involved in the professional development in the field of ICT and **8.4%** of schools monitor the number of teachers that participate in CPD connected to integration of ICT in the curriculum and almost all teachers participate in some form of training in the field.

- <u>TEACHER CONFIDENCE</u> - in **25.3%** of schools teachers have basic knowledge of ICT but they lack the confidence to apply them in the classroom; in **50.5% of school's** teachers feel confident to integrate ICT in the curriculum and only **14%** integrate it in their daily teaching practice.

- <u>SPECIAL EDUCATIONAL NEEDS</u> – In **58.9%** of schools less than half of the teachers have completed ICT & Special needs professional development; **22.1%** of schools report that all teachers are involved in special education needs; **11.6%** of schools have teachers that are competent in the use of technology to support students with special education needs and **7.4%** have teachers that use a wide range of technologies to facilitate the inclusion of students with special educational needs.

- <u>INFORMAL LEARNING</u> – **32.6%** report little sharing of TEL ideas and good practices among teachers; **34.7%** report that the sharing takes place occasionally; while **23.2%** of schools have teachers regularly sharing ideas and good practices with their colleagues; and **9.5%** of schools supporting and facilitating the peer-to-peer learning in ICT.

TEL CULTURE

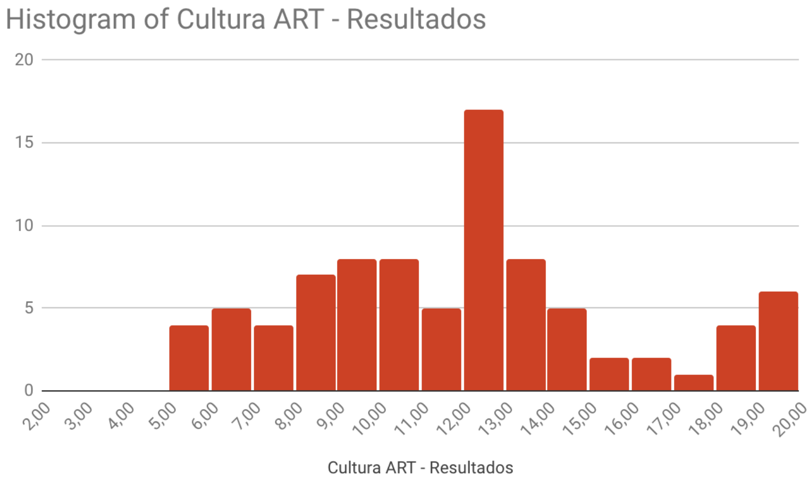


Figure 17 Results for Portuguese Schools in the Field of TEL Culture

The maximum possible grade in this field is 20 points. The minimum to be awarded the Digital School status is 11. In this particular area we see that there is a culture of integration of Technology Enhanced Learning and schools are well positioned in it (Figure 17).

- <u>ACCESS</u> - **35%** of participants report that teachers and students have limited access to TEL resources; in **30.4%** of schools the access is regular and for **25%** this access is available throughout the school; in **9.8%** of cases this access is also available to the local community,

- <u>EVIDENCE OF USE</u> – **32.6%** of schools there is little evidence of it and **43.5%** have some visible evidence of the use of TEL**;** in **15.2%** this evidence is visible in all areas throughout the school and **8.7%** of schools disseminates and shares examples of good practice beyond their own school community.

- WEBSITE ONLINE / PRESENCE - **25%** of schools have an active presence online; in **18%** of schools involve their teachers in the creation of the online content; **41.3%** of the schools have an active and updated site and **15%** use the website as a mechanism to engage the local community.

- PROJECTS **- 42.4%** of schools reported that some teachers use ICT in the development of their projects; **35.9%** of schools are involved in projects that integrate ICT; **9.8%** use ICT for interdisciplinary work and large-scale projects and in **12%** of schools students and teachers regularly develop projects of small and large scale,

- ORGANIZATION AND COMMUNICATION – **18.5%** report being at the level where they only have email address and use this for basic levels of correspondence and communication**; 30.4%** present some communication between school and external stakeholders via email or text messaging while **40.2%** make regular use of ICT to communicate with teachers, parents and other stakeholders**;** in **10.9%** of schools there is an encouragement to parents and the wider community to use ICT to communicate with the school. Teachers, students and parents have online access to student documentation and timetables.

TEL RESOURCES AND INFRASTRUCTURE

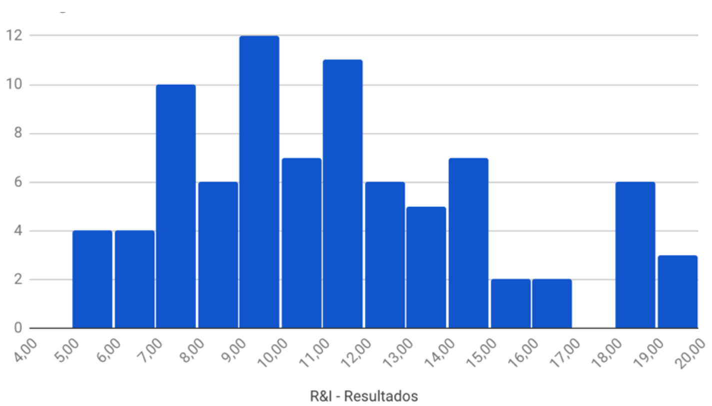


Figure 18 Results for Portuguese Schools in the Field of TEL Resources and Infrastructure

The maximum possible grade in this field is 20 points. The minimum to be awarded the Digital School status is 14. A large fraction of schools are below the minimum threshold (Figure 18).

- PLANNING FOR ACQUISITION OF RESOURCES – In **34.1%** of schools there is only a basic ICT plan focusing on acquisition of equipment; for **31.9%** the planning includes standardisation of ICT equipment; **12.1%** procurement, planning and standardisation of ICT equipment is the norm; **22%** have an integrated approach that considers the full operational cost of ICT and technical support provisions.

- INTERNET ACCES AND WIFI AVAILABILITY - in **12%** of schools there is only one internet connection; in **30.8% of schools** most classrooms have computers connected to the internet; **26.4%** have good and fast connection that extends to the whole school and in **30.8%** all teachers and students have safe access to internet and online resources that are also available remotely.

- <u>TECHNICAL SUPPORT</u> - in **33%** of schools the technical support is provided by volunteers most of the time; in **14.3%** of schools the support is provided by an external company via a call-centre; **31.9%** report having a consistent and organized support service; in **20.9%** support is planned and integrated in the ICT plan that also includes provisions for updates of systems on a continuous basis.

- <u>DIGITAL CONTENT</u> - **61.5%** reported having only a limited amount of TEL resources; **20.9%** on the other hand report having the appropriate resources and able to provide support to all levels.

- <u>ICT EQUIPMENT</u> - **13.5%** of schools don't have computers in all classrooms; in **40.7%** of the cases some classrooms have projectors and computers and other equipment for TEL activities; **27.5%** have good coverage of internet as well as well-equipped rooms and **18.7%** of schools there are also mobile devices for students.

GLOBAL RESULTS

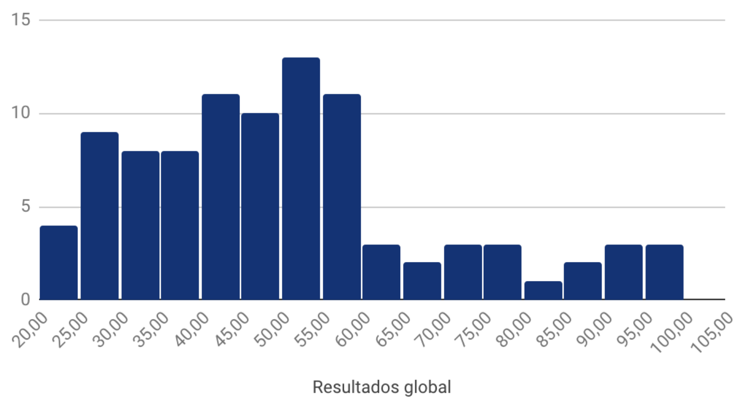


Figure 19 Global Results of the Self-Evaluation Test of DSOE in Portugal

The minimum value to be considered a Digital School, respecting the minimum for each strategic field, is 58 points. The maximum that can be obtained is 104. Many schools (~20) attained the minimum level to be considered a Digital School (Figure 19). The goal is still to reach 100 schools participating in the questionnaire in order to initiate the validation scheme. The validation will require a visit to schools willing to be awarded in order to verify and validate the referred status. The first validation round will be done with the support of a member of the validation team of Digital Schools of Europe.

In this chapter I presented the state of the art in a field that is, and should be, rapidly changing. The 4th industrial revolution is upon us and educational systems have to adapt swiftly. The key competences, for teachers and students, the teaching and learning paradigm, the training of educators, the school setting, the curricula and policies are all part of an extreme complex machine that is heavy and very hard to change. The work presented in my thesis is an attempt to understand what is necessary to succeed in such an endeavour.

2. The science capital and the impact of science communication

Learning is something that we do every day throughout our lives. It takes place in formal settings, where learning is intentional, organized and structured. It happens in non-formal instances, such as experiences we have in science centres, museums, etc. And more commonly it happens in informal ways, spontaneously and usually in a non-structured or organized way (ICS, 2011).

These ways of learning are complementary, and each have a particular relevance in different parts of our lives. Learning is a lifelong endeavour that requires multiple experiences in an interdisciplinary manner (Ainsworth & Eaton, 2010). When it comes to science learning the field takes on a further diverse aspect as it involves several aspects of the world around us. In a school setting, where formal learning is the preferred approach, science learning is split into many different disciplines and sometimes the construction of a solid scientific literacy can suffer from the lack of a broad perspective. But this is something that we will handle in future chapters. Here the main aim is to discuss the power and importance of science outreach in the construction of a solid science literacy for the public it touches.

In general, we can measure the level of development of a society by measuring its **science capital** (Archer et al., 2013), the aggregate of science related knowledge, the attitude towards science, the experiences every individual accumulates throughout their lives, the levels of daily engagement with science, the people surrounding their daily experiences that are science literate and their everyday experiences with science (STC, 2017). A science literate society is better prepared to make wise and informed decisions - or at least it should be. Science illiterate citizens are more likely to be manipulated and are more likely to take unwise decisions. All societies should invest in science communication as a means to increase their science capital. It is important for our lives in general, to ensure a fair range of science expertise is available in all different domains, to keep our cultural heritage and to ensure freedom (Bultitude, 2011). The dimensions of science capital encompass several important components (Nomikou, Archer, & King, 2017):
1. Scientific Literacy
2. Science-related attitudes, values and dispositions
3. Knowledge about the transferability of science
4. Science media consumption
5. Participation in out-of-school science learning contexts
6. Family science skills, knowledge and qualifications
7. Knowing people in science-related roles
8. Talking about science in everyday life

Scientific Literacy as defined by the OECD/PISA is (ICS, 2011)

- Scientific knowledge and use of that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues;
- Understanding of the characteristic features of science as a form of human knowledge and enquiry;
- Awareness of how science and technology shape our material, intellectual, and cultural environments;
- Willingness to engage in science-related issues and with the ideas of science, as a reflective citizen.

These are important components for the task of preparing the scientists of tomorrow. There is a growing concern related to student interest in pursuing careers in scientific disciplines but, more concerning, is the fact that countries with large numbers of high achievers in science are presenting lower percentage of students with an in interest of pursuing scientific careers. It seems that the process that is taking them to have a high achievement status is also killing the motivation for a possible career in science (Sjøberg & Schreiner, 2010). Teachers for sure play a key role in inspiring and preparing the next generation of scientists but in many countries around the world they need training, not only in the specific science subject domains but also, if not primarily, in the use of Technology Enhanced Learning (TEL) (ICS, 2011).

In the European Commission Education and Training Report 2018 (EC, 2018a) an alert is made related to the impact of teaching practices and low achievements in science which will inevitable drive students away from choosing STEM related careers. The conclusion presented in the report suggests that a combination of teaching practices is the best option to improve the performance of low achievers. The same document also states that the quality of initial teacher education, the promotion of effective collaboration among teachers and the participation in professional development programmes helps educators understand and better address the different needs of different students and, as such, positively impacts their learning outcomes.

The report refers to the Portuguese strategy for citizenship education as a positive highlight (DGE, 2017) but the fact that the teaching population is ageing, with less than 1% of teachers under 30 years of age (DGEEC, 2018), presents a major challenge for the future, and this certainly has a non-negligible impact on how some subjects are being delivered in classrooms across the country. This might be the reason for Portugal having graduates in natural sciences, ICT and mathematics below the EU average. The numbers compared to the ISCED 2015 (International Standard Classification of Education) can be seen in Figure 20

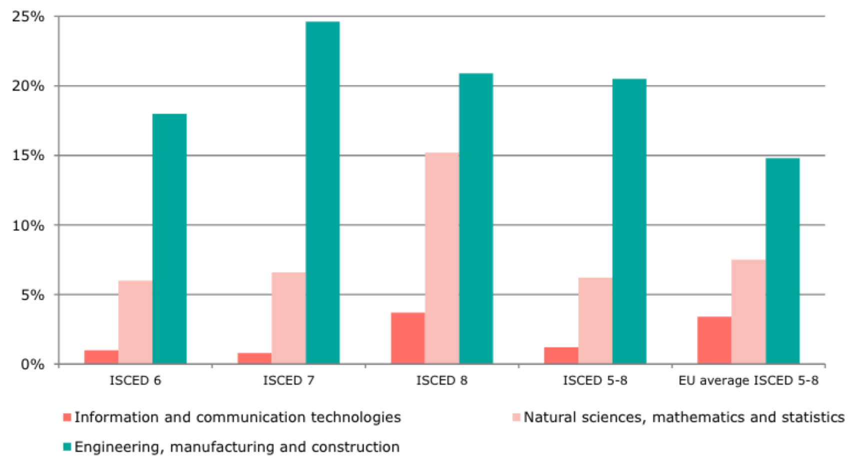


Figure 20 STEM students as share of total number of students per ISCED (2015) (ISCED 6 – Bachelor or Equivalent, ISCED 7 – Master or Equivalent, ISCED 8 – PhD or equivalent)

The same report highlights that half of the adult population has a low level of education attainment, reinforcing the need for a solid and continuous science communication programme. In 2018 the EU recommended that Portugal takes measures to increase the skill levels of the adult population, including digital literacy, by strengthening and broadening the coverage of the training component in adult qualification programmes. This includes of course the training of educators where ICT competences are still a major challenge when we try to introduce new trends for science education (Chapter 6.4).

The problem of lack of interest of students for STEM subjects is a source of concern in all developing countries (King, Nomikou, Archer, & Regan, 2015). Schools and teachers are key to addressing this problem. Improving the competence profile of teachers via a solid training and support environment can hold the answer to this problem. In Chapter 6 a full strategy for community building and a competence profile for teachers is presented. In (King et al., 2015) we find a very interesting collection of references on what are the key factors influencing student interest and attitudes towards science and the role teachers play in it.

In Portugal the large network of science centres is greatly contributing to the creation of science awareness and greatly contributing to the construction of the science literacy of the population in general. In those centres visitors have the opportunity to be involved in a more interactive experience and have a sense of being involved in scientific research. In general, these science communication actions focus on exhibitions and the production of digital pedagogical material. However, as presented by (Delicado, 2006), these centres and museums have a limited reach. They are in general expensive and can only support a small fraction of the school network. Underprivileged or socially excluded communities are the ones that benefit less from these initiatives. This is where the role of NGOs and other similar volunteer efforts are important.

To be noted, and as presented in this chapter, there is a difference between the communication of science, the enhancement of science literacy and a deeper understanding of its nature. There is still a gap between the interest in science related topics and the motivation for possibly taking a career related to STEM. Training and empowering teachers with the necessary skills to properly facilitate science learning is a path worth exploring.

In fact, and as reported in (EC, 2005), the public in general expect scientists to be active supporters of science awareness and to share their research with the public. In all research projects funded by the European Union, it is mandatory to integrate a dissemination component. Not all scientists are prepared for this task and in fact several research networks are investing in preparing scientists to communicate with the media, with teachers and with the public in general. Participants of these workshops learn how to identify different approaches to engage with schools; how to choose the proper tools and resources; how to engage with teachers; how to use Inquiry Based Learning as a model; how to prepare their science to be understood; and if possible, how to provide a hands-on opportunity for students to learn about their research[11]. A list of useful tips on how to engage students and teaches is provided in (Doran, Naze, & Heward, 2010). A few examples presented in this booklet are described in chapter 3 and chapter 4.

The celebration of International Thematic years can provide cost-effective opportunities to promote large scale science communication activities. The International Year of Astronomy 2009 (IYA2009) was a great example and one of the most successful celebrations, gathering representatives from over 148 countries. Some of the global projects promoted during IYA2009 are still living legacies of the ephemeris as presented in Chapter 4.3. Millions of people worldwide were impacted by the project with a long lasting legacy (Russo & Lindberg, 2010). In Portugal IYA2009 was coordinated by SPA (Portuguese Astronomical Society) under the coordination of Prof. João Fernandes (Dpt. Mathematics and Astronomical Observatory of University of Coimbra). Over 440 institutions helped organize more than 4 000 activities: talks and observation sessions in schools, exhibitions, teacher training, festivals, TV shows and more. The legacy of this celebration is still visible around the country (Frade, Doran, & Fernandes, 2011).

[11] http://www.europlanet-society.org/outreach/science-communication-training/1st-training-workshop/

Science communication is desirable and necessary for the development of the science literacy of the public in general. The lack of it will end up in the lack of participation of citizens in the decision-making process of important issues such as climate change, plastics pollution, etc. The lack of basic scientific knowledge with a deep understanding is a menace to humans and can lead mankind to its own extinction. Lack of understanding of our place in the cosmos, of our dimension and scale induces an illusion of self-importance, the delusion that we have some privileged position in the Universe (Sagan, 1994). Fake news is invading our lives and the lack of a solid general literacy can bring very dangerous outcomes. Fake news is not only those appearing over the media, placed on purpose to influence some decisions, it can also be simply the fact that people are only reading headlines without critically thinking of what is behind each flashy title.

Imagine for instance finding such titles in the headlines of a newspaper (Doran, n.d.):

- It is already possible to repair damaged tissue in human skin;
- A drop of water might trigger a new life
- Scientists are able to observe things that happened in the past

They will certainly attract the reader as something outstanding when in fact they are just describing phenomena present and occurring in our everyday life:

- Normal process of healing;
- Watering a plant;
- Observing the constellations in the starry sky, for example (in fact, we can only see the past, but this is the subject of another debate).

The way information is conveyed to the general public can often misrepresent the reality behind the fact. Science literate individuals with key competences and basic science literacy are more well equipped to properly interpret and make wiser decisions on their sources of information. Conspiracy theories are abundant and greatly feed on the lack of scientific knowledge from its followers: Flat Earth, Moon Landing Hoax, Aliens, campaigns against measles vaccination, to name a few. Although disturbing some of these are not harmful, but some are potentially deadly.

Science communication can help minimize the misinformation but is not enough. Science literacy requires much more than listening to scientific facts, it requires active involvement, motivation and the will to know more. Education and the construction of knowledge, information literacy (the set of learning and critical thinking skills necessary to access, evaluate, and use information efficiently; the capability of promoting academic integrity and research) should not be understood as a commercial product and, as such, should not be for sale. Governments and private institutions, the society as a whole, have to realize that investing in scientific education of citizens is paramount to fostering the promotion of personal enrichment for each individual and ultimately the ability of this well-educated cohort of individuals will help build a nation with solid foundations, capable of making sound decisions tailored to the specific needs of each country (Doran, n.d.).Scientists sharing their research is becoming more and more common. Research infrastructures such as CERN, ESA, ESO, etc. invest in the production of teaching kits where data from their repositories are used to bring a real research experience to their users. If we think about real research reaching the public in general or schools in particular, we can define the “science food chain” that nurture science literacy with the following levels:

- Science production – institutions or individuals that generate knowledge that need support in order to create content dedicated to science communication,
- Science tutor – well prepared individuals with adequate resources that act as a promoter of science. This role is often assumed by teachers. With the adequate support and empowerment from their institutions, they can act as powerful replicators and disseminators of science outreach,
- Science learner – often students that will further nurture the science chain by bringing home the knowledge they have acquired.

Often, science institutions invest heavily in the first level of this chain and believe that making their materials available on the internet will suffice. Without the proper support, and preferably some training, the materials freely available might not reach the end user. Teachers find hundreds if not thousands of resources freely available on the web. Taking the example of astronomy, and considering that they choose trustable sources, they will still find hundreds of resources for each specific topic they are willing to address. This is not necessarily a bad thing, but reality tells us that they won't benefit from the vast majority of the resources made available. Teachers are busy people, with a very dense curricula to cover, usually serving a large number of students and frequently having to deal with the complicated specific needs of their audience. Passive delivery of science content is better than no delivery at all, but if we want to reach out to students and promote a strong science literate society, active solutions are necessary.

In 2005 the European Commission conducted a study to assess the attitude of Europeans towards science and technology. The main interest was to analyse the following items (EC, 2005):

- European citizens' interest and level of information,
- Image and knowledge of science and technology
- Attitudes towards science and technology
- Responsibilities of scientists and policymakers
- The public's perception of European scientific research

This study was repeated in (EC, 2010). The main results show that, in general, European citizens are interested in new scientific discoveries and technological developments. In general, there is a feeling of being well informed but 91% of responders never or hardly ever attended public meetings or debates. There is a lack of insight into the work of scientists but feel that scientists should communicate about their work, although they consider that this is not being done efficiently. The study also shows that those that feel informed about new scientific discoveries are much more likely to have a positive view of science and technology than those who are not at all interested or who feel not at all informed. The study of 2005 claims that there seems to be a positive impact from the "science and society" action plan promoted by the European Commission with its framework programmes. The participation of Portugal in some of the projects funded under the Science and Society action plan are presented in chapter 1. The study also presents that there is a stereotyped vision of "machine against man" with the fear of the negative effects of technological development on employment and the distress scientific and technological progress can cause. There is concern about a lack of transparency in science development and the limits posed by ethics and morality. In Portugal 35% of responders state that they are not at all interested in scientific discoveries and technological developments, a very disconcerting percentage. Over 58% of the Portuguese participants feel poorly informed about these topics. Also disturbing is the percentage of responders in Portugal (65%) that think that scientists, because of their knowledge, have power that makes them dangerous. Yet, 60% of the respondents think that scientific research which adds to knowledge should be supported by the government.

In 2013 an important new survey was conducted focusing on the area of responsible research and innovation (EC, 2013a). The survey focused mainly on engagement, impact, attitudes, ethics, young people, gender and open access. The study presented questions such as:

- What is the level of involvement citizens should have when it comes to decisions made about science and technology?
- Which people or groups are the best qualified to explain the impact of scientific and technological developments on society?

In this study, contrary to what was found in 2005, 58% of respondents on average didn't feel informed about development in science and technology. Around 66% were interested or even very interested about developments in science. Again, Portugal stands out on a negative note where 50% of respondents were neither interested in nor informed about developments in science and technology. Under half of the respondents (47%) had studied science or technology, either at school, university, college or another location (a decrease when compared to the 2005 survey but nonetheless very worrying). Over three quarters of respondents (76%) have no family members with a science or technology related job or university qualification, which negatively impact the science capital all over Europe. In Portugal 51% believe that public dialogue is required when related to decision-making processes about science and technology. 77% of participants think that the influence of science and technology on society is positive or very positive. In general, there is also a positive attitude towards the opportunities science and technology will bring to future generations, but the same percentage believe that science and technology could be used by terrorists in the future. Ethics is also an important and very relevant topic with respondents agreeing that researchers should receive mandatory training on scientific research ethics. In what concerns Young People and Science over 65% of the participants think that little is being done by governments in order to stimulate young people's interest in science. Around 70% agree that an interest in science improves young people's culture and prepares youth to act as well-informed citizens besides having better chances in getting a job. The importance of scientific education in stimulating young people's creative thinking scores highly with 84% agreement. Equality between women and men is also finding agreement in 86% of respondents.

All these studies are bringing a very strong case towards the importance of research and science education. They are also revealing a lack of science literacy and awareness of the scientific method and the general understanding on how science is done.

Promotion of science awareness can be done is several different ways. Scientists can share their research by publishing their results in press-releases, with language that is suitable for a general audience, engage in public talks (to the public in general or supporting schools), etc.

During IYA2009, where several different science communication techniques were used, the impact was immense and left lots of seeds all over the world. The project acted as a catalyser of interest, an aggregator of knowledge, tools and resources - but general awareness about a topic doesn't mean knowledge and understanding of it. Science education is the only way to ensure participants of any communication action are not just passive consumers of information. It is indeed true that the ratio of investment to audience reached is much higher when the model of massive dissemination is used as opposed to direct contact with schools - but this model doesn't create a long-lasting legacy and frequently the shared information is quickly lost in the memory of the participants. The growth of one's science literacy requires a more active role for end users. Frequently, the power of a well-informed educator is completely under-rated and, in fact, in the science communication discourses of research facilities, rarely do we see teacher training as a priority in investment(Doran, n.d.). A well-informed teacher will directly impact every year 20 to 100 students, each student has the potential of being a replicator by sharing their learning with their families. Teachers and students can expand their impact by sharing their experiences with a potential of reaching out to hundreds of members of their local communities. This was the main objective of the Galileo Teacher Training Program, a legacy of IYA2009 that aimed at empowering educators to bring astronomy, and in particular research in this area, to schools all over the world. This initiative will be further explained in the next chapter.

In (EC, 2014) citizens were asked about what they would like research to focus on. A list of 13 items have been selected: Fight against climate change; protection of the environment; security of citizens; job creation; energy supply; health and medical care protection of personal data; reduction of inequalities; adaptation of society to an ageing population; availability and quality of food; transport and transport infrastructure; education & skills; quality of housing. In general people think that positive impact on the presented issues can be achieved through science and innovation rather than through people's action and behaviour. The priority trend in Portugal when it comes to science and innovation follows more or less the rest of the countries participating in the study. The number one priority is job creation followed by health and medical care. The third priority is education and skills, but Portugal's score is among the lowest, which means that responders in our country find this topic less important than responders in the other member states although more than 61% of Portuguese responders think science and technological innovation will have a positive impact on education and skills. In general responders have a high degree of assurance that science and technological innovation can help address the presented problems.

This was indeed a very good action. However, in order to make educated decisions the public needs to have awareness related to the different topics being presented to them. When participants were asked if they ever studied science at school, university or somewhere else an average of 43% or responders said **no** (46% in Portugal). It is also necessary to take these numbers with caution, having studied science doesn't mean having a fair literacy on the subjects presented at school.

In a more recent Eurobarometer study on "European Education Area" (EC, 2018b), we find very interesting responses where in the majority of respondents in all Member States think that "increasing the teaching of creativity or critical thinking in European schools or universities would be useful. Similarly, in all countries, a majority of respondents agree that it would be a good idea to promote cross-disciplinary curricula by creating more opportunities for young people to study and work together across departments and disciplines". This is highly aligned with the initiatives presented in this document, more specifically chapter 6 and chapter 7.

There is an urgent need to improve the competence profile of teachers in terms of content knowledge, innovative pedagogical trends and on the use of hands-on activities to facilitate science learning. How to introduce real research experiences in classrooms and what is necessary to empower educators and motivate students is the main aim of the work presented in this document.

In summary, science communication and science education are key for a healthy development of all societies. Initiatives should be put in place to empower and motivate young generations to pursue a career in science.

Final considerations:

We started this chapter with a discourse about the different ways of learning. By now we state our case related to the importance of science literacy in the construction of our own knowledge. When emerged in informal learning experiences such as visiting a science centre, a museum, a planetarium or similar places we can have the feeling of being completely embedded in a scenario where there are no tests or exams waiting at the end of the line. We live the experience as a fun activity, very often filled with hands-on opportunities and the learning takes place naturally. However, these moments, by taking place in our lives, usually, in an unstructured way, might leave holes in our science literacy. Thus, the construction of a solid base of knowledge is fundamental for us as a species. Understanding what science is and recognizing the value of the scientific method is a powerful way to ensure that the construction of our knowledge database is well grounded, and that concepts and competences are properly supported.

The integration of formal, informal and non-formal learning in the experiences of a student are key to provide a holistic approach and enabling gains in diverse knowledge and skills. There is no recipe for this experience and in the end each individual will gain a different insight according to the opportunities provided (Ainsworth & Eaton, 2010).

Science outreach is usually taking place in informal and non-formal settings. The learning that takes place in formal settings, such as schools, are of a completely different nature and the way we deliver knowledge and foster key skills varies enormously from country to country, school to school, classroom to classroom. The next chapter is devoted to discussing this part of knowledge construction and skills development. What are the best practices that we should adopt when learning in the 21st century? Changing the attitude towards teaching and learning is a hot topic at the moment and changes in the Educational Policies taking place in Portugal will be discussed later in the document.

Schools are where we determine the future of mankind, where we see talent flourishing, but they are also places of anguish for many educators who struggle with few resources, dense curricula — in many cases not connected to real life — and an exam performance-oriented school vision (Doran, 2014). These educators, sometimes struggling to accomplish almost impossible missions, come very often unprepared, and have little or no support to take up such demanding responsibility. Educators have to prepare their students for a future they don't know, to perform in careers that probably have not been invented yet, ensuring equity and inclusion. They have to prepare students to embrace innovation without fear, to be critical thinkers, resilient and persistent, to learn how to learn. The role of those supporting educators is to provide the best support we can, to empower them with innovative tools and resources, to provide them relevant content delivered in useful and modern formats. In chapter 3 we will present a few ideas on how to bring real research experiences into classrooms and their possible impact.

3. Science Education/Research in Classroom

In the previous chapter I presented the importance of science literacy to all individuals and how this should be a lifelong learning enterprise. Although the concept is straightforward and the agreement is general, the skills to achieve such ambitions are not something we carry with us during our lives, although we are all natural born scientists. Observe a baby or a toddler and you will understand this statement. The moment they start to be able to grab things and bring them to their mouth they start using inquiry-based learning.

Bringing research experiences closer to student lives is key for their development. As mentioned in the previous chapter teachers need support in improving their content knowledge as well as their methodology. The promotion of talks, workshops and observation sessions in schools can be a very important mechanism to boost the motivation and interest of students and act as a supporting action for educators. However, without promoting the active engagement of participants the effect of such actions is usually not long lasting.

Astronomy is a subject that sparks curiosity and in general is very appealing to students and teachers alike. However, besides provoking curiosity, and sparking creativity and imagination of the audience it is far more important than just an amusement show. It is one of the sciences were the laboratory is rarely inside walls and the data acquired with cutting edge equipment is, in general, freely available on the internet. In this chapter I present a few experiments where students are invited to work alongside scientists and help them with their research.

3.1. The Martians of Brandoa - The impact of research experiences in the classroom

This first example shows the importance of bringing a real research experience to schools. This experience demonstrates the importance of treating each student as an individual and recognizing that all individuals have the capacity to learn, be excited and interested in several topics. It shows that there are many different ways to present scientific topics and spark student interest towards them (Ainsworth & Eaton, 2010). While working with teachers in the European Hands-on Universe project (described later in this document) we had the opportunity to meet a teacher working in Brandoa, a difficult neighbourhood in Lisbon. According to her, her students were low achievers with severe school attendance problems and very little interest in science subjects. However, one of the students did have a particular interest in the planet Mars. The class started participating in the project in the 7th grade and was only supposed to run for one year. The project was such a success that the project was extended for a second year and in the end the whole school started to participate in projects of a similar nature. We requested a planetary scientist, doing research about the red planet, to visit the school and try to run a few outreach activities with them. The planetary geologist, José Saraiva, from Instituto Superior Técnico decided to involve them in one of his research studies. In order to test software being developed with the aim of automatically tracking craters on Mars they needed supportive evidence to validate the accuracy of the measurements being obtained by the software. Saraiva developed a programme to prepare the students for this task. The programme involved several different components (Figure 21):

- Measuring craters in a selection of images,
- Building 3D glasses to observe Mars anaglyphs from Mars Express mission,
- Recreate features on Mars using clay,
- Making craters with different objects and with different compositions,

- Simulating rovers on Mars
- Finally, identifying craters on the surface of Mars in a particular set of images to help validate the software results.

Figure 21 The Martians of Brandoa working on the different proposed activities © NUCLIO

Their attitude towards school and in particular science learning was forever changed. The teacher, who later confessed that she was considering changing her profession, decided to take a masters in astronomy education that resulted in a platform for other teachers interested on the topic: http://martenaescola.ccems.pt/. In the learning process they acquired several key skills related to the use of mathematics as an important tool to understand physics. These students transited to the next school year with positive grades in maths and physics, something completely unexpected by their teachers. Their families, usually absent from school, came to see their children share their achievements with the whole school community. One of the mothers came to me and shared a very nice story where her daughter told everyone at home to be quiet because they were presenting a story on the news related to her field, "Astronomy". The impact on the teachers, students and families involved was so evident that we immediately knew this was the way forward. Recently one of the girls involved in the project, Bárbara Heitor, currently studying to become a teacher, replied to a post her teacher made on Facebook saying that the project had a good impact on her (Figure 22).

Figure 22 Statement of one of the students involved in the project

3.2. Hunting for Open Star Clusters: Exploring Science Research in the Classroom and the importance of teacher training

The second project to promote science research at school was in partnership with André Moitinho, an expert in Open Clusters of Stars and researcher at the Faculty of Science at the University of Lisbon, and currently president of the Portuguese Astronomical Society. André visited Escola Secundária da Cidadela and invited the 12th grade students to collaborate in an experiment whose aim was to find open clusters using a new technique. The students' mission was to explore a database of O stars (Figure 23), a type of star, and try to find if they were part of an Open Cluster of Stars. In order to do that they had to make a careful selection of objects and use robotic telescopes to observe them.

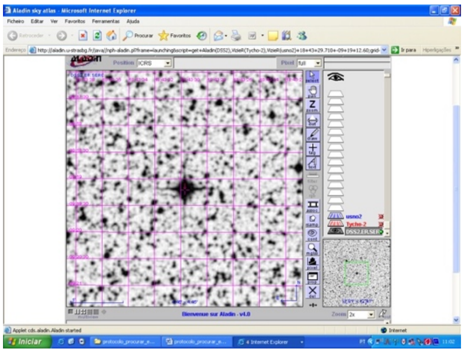


Figure 23 An image of the Digital Sky Survey Analysed by the Students

The students surprised everyone when we realized they spent their weekend analysing data. They autonomously discovered, through the search engine made available to them, which were the interesting objects, which were the ones already studied by scientists and which were the suitable candidates for further study. A genuine excitement took over the students when one of them spotted a gas cloud that seemed not to have been previously detected. Some of the students even suggested a few new science projects.

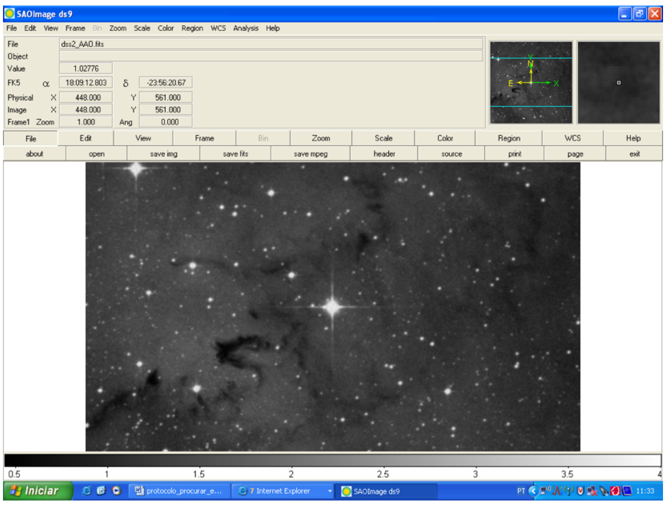


Figure 24 A gas cloud detected by one of the students participating in the project

They learned how to use a database of images, the Digital Sky Survey, they learned to search for scientific information in paper archives and to compare images in different wavebands while searching for a positive result (Figure 24). The observations were made using the Faulkes Telescopes, a research quality robotic telescope available for free to a selection of schools. The students didn't have time to pursue the project to the end, but the process was really rich in terms of its learning outcomes and the attitude of the participating students towards science and a possible science career. The motivation was similar for girls and boys participating in the project. In 2008 this project won the 3rd prize in the European Contest Catch a Star promoted by ESO[12].

Although the experience had a huge impact, it could not be replicated by the teacher. It would be necessary to have the continuous support of the scientist in order to ensure continuation. The project did have a considerable impact on the students and teacher, but was a one-off event. This is due to several reasons, the project was introduced in the project area, a slot in the curriculum schools had at the time of implementation of the project to run projects with their students. That is the reason why we were able to engage 12th grade students. The science being proposed had to be done with the support of a scientist. Unfortunately, it is not easy to get such strong support and commitment from a scientist. In general, they are very happy to promote a few talks and some limited hands-on activities to schools, to produce educational material, but rarely have time to devote supporting an enterprise like the one described in this chapter. This is totally understandable as this is not their main role. This project was also possible because NUCLIO has in-house expertise to provide the necessary support to the teacher.

3.3. IASC – International Astronomical Search Collaboration

Citizen Science is currently a highly trending model for science communication. It is being largely used in science domains where the quantity of data is too large and automated procedures are not efficient. For example, when trying to count craters on the surface of a planet (such as the case of "The Martians" presented above), or counting spots on the solar surface, or finding animals in the middle of a forest, among other very interesting research opportunities. Usually these projects, make their data available to the public and a short tutorial enables participants to actively take part in a specific research topic. Zooniverse[13] is a very nice example and one of the most popular citizen science research projects. It has over 1.700.00 registered volunteers that can choose the project they will participate in areas such as: astronomy, biology, history, literature, etc. The example presented in this chapter is related to the International Astronomical Search Collaboration (IASC)[14]. It is a project coordinated by the Harding Simmons University in Texas that involves students in the discovery and/or confirmation of new solar system objects, usually new asteroids. Currently the project reaches over 60 countries and over 1,000 asteroids, comets and other small bodies of the solar system have been discovered by students from 12 to 18 years old using it. The images are obtained by the ARI Observatory, WKU Observatory, SSO Observatory, MLSC Observatory and TSU Observatory which are immediately distributed to volunteer schools that have 2 to 3 days to analyse the images and present results. The potential new discoveries are confirmed by the IASC team and after confirmation are

[12] http://vintage.portaldoastronomo.org/noticia.php?id=744
[13] https://www.zooniverse.org/
[14] http://handsonuniverse.org/usa/participate/iasc/

sent to the Minor Planets Centre, the international entity that verifies the data. After confirmation of the discovery and follow up measurements the discoverers are entitled to name the object they have discovered. The Portuguese participation, coordinated by NUCLIO, started in 2007 and today has over 60 schools participating in the project. Over the years we have had hundreds of preliminary, and dozens of provisional, discoveries. The preliminary discoveries are those needing further observation in order to be confirmed - objects that are successfully tracked again receive provisional status. After a few more observations the Minor Planet Centre (MPC) is able to determine the orbit of the object. In 2017 we had the first official confirmation from the MPC that an object discovered in 2012 by a team from 4 schools[15] could be named by the discoverers. The asteroid's name will be "Lusitano".

The first asteroid discovered in Portugal in the framework of this programme was attributed to a team of students from Escola Secundária de Alvide, Cascais (Figure 25) in 2011 - the first Portuguese, in Portugal, to ever discover an asteroid. The students and their school received a lot of media attention and the mayor of Cascais even presented the students with their own telescope[16].

Figure 25 Students of Escola Sec. de Alvide who discovered the first official asteroid discovered by Portuguese © NUCLIO

The students' work was to analyse a collection of 3 images using the Astrometrica software (Figure 26). The software is connected to the MPC database and automatically identifies already known objects. Students have to observe the 3 images and try to find unknown objects that change position from one image to the other.

Figure 26 Example of an image studied by students when searching for new asteroids © NUCLIO

[15] http://vintage.portaldoastronomo.org/noticia.php?id=790
[16] http://vintage.portaldoastronomo.org/noticia.php?id=769

In general, this work can't be done within classroom hours and usually the time they have to analyse the images, after they are made available to each team, is very short. Frequently they will analyse them in their own free time, with the support of their teachers. All participants are very motivated to participate in the project and enthusiastic about their contribution to science. Their work helps scientists determine the orbit of unknow rocky objects tracking possible threats to our planet.

Whilst the team from Alvide were officially recognised as the first to discover an asteroid in Portugal, in fact Salvador Bruschy and his teacher Leonor Cabral from Escola Secundária da Cidadela, who pioneered the project in Portugal, had previously discovered a new asteroid, though this was only made public after 2011.

A few of the pioneer teachers in the project, from Portugal, France, Poland and Ireland, participated in the Comenius project "In orbit with Europe". This project invited teachers and students from the participating countries to go deeper in some of their discoveries and to collaboratively calculate the light curves of asteroids[17]

In the latest campaign, 2018, teams introduced to the project by NUCLIO identified over 233 new provisional asteroids. IASC now has a new contract with NASA and will soon start investing in teacher training to further enhance and enrich the programme. As in most citizen science projects the participants are acquiring some competences in performing the necessary research, but they are not necessarily increasing the science literacy related to the topic they are researching. In the case of IASC, students learn how to analyse data and get a deeper understanding on how scientists work when trying to find this type of objects. However, their understanding about the very nature of such objects and why this research is so important might not be at a desirable level. This will be the next phase for this project that in 2019 is aiming to reach 100 nations.

The examples presented in this chapter had different levels of support and investment in the competence profile of the teachers involved. Projects with a stronger legacy were those where the teacher training component was more structured and accompanied the entire activity. The lessons learned and the impact of the different projects presented act as a guideline for the structure proposed in the next chapter. The need for continuous professional development was evident in all of them. Despite the motivation presented by the students and the engagement of educators the necessary competences for teachers to independently integrate research in the classroom and the deeper learning expected from students seemed not to be present. Teacher training associated with community building seems to be the road ahead. The next chapter is devoted to the description of several attempts in this direction which are then finally assembled and measured in chapter 6.

[17] http://vintage.portaldoastronomo.org/noticia.php?id=886

4. From Teacher Training Towards Community Building and Competence Profile Implementation

In the previous chapter a few interesting examples of cutting-edge research in classroom projects were presented. Their impact, in my personal opinion, was obvious as well as the feasibility of their implementation, as long as the appropriate support is present. In all cases teachers had an important role in the development and support of their students. Students certainly acquired important key competences and started appreciating science in a completely different way. Nonetheless, the replication of these examples requires continuous external support. The missing component is the training of teachers so that they can autonomously integrate in their teaching some examples of cutting-edge research that can enrich the learning of their students. Although the integration of new science without support can be limited, the empowerment of educators has a ripple on effect and a strong sustainability characteristic.

As presented in Chapter 1, training teachers is a key action in preparing future generations and to ensure societies hold enough science capital. The professional development of teachers requires certain items. The methodology used to train teachers should be no different than the methodology they should use with their students. If we recognise student-centred approaches as those ones with the most impact on deeper learning and transferability of knowledge, this is the model to be used to put educators being trained at the centre stage.

According to (ICS, 2011), the development of teachers should encompass the following items:

- Deepening and broadening of knowledge of science content.
- Modelling the teaching of new content as well as best teaching practices (inquiry, constructivism, multiple intelligence, alternative assessments, etc.) to help teachers implement what they have learned as part of their professional development experience.
- Preparing teachers on how to engage their students in scientific investigations.
- Encouraging teachers to share successful teaching methods and materials that they have either developed themselves or are using from another source.
- Providing the opportunity for teachers to participate in courses on continuing education, science specializations, or towards a graduate degree.
- Integrating science with technology, social sciences, language and the arts.
- Establishing a strong foundation in the pedagogy and didactics of particular disciplines and their contribution to measurable improvement in student achievement.
- Devoting sufficient time, long-term support and resources to enable teachers to master new content and pedagogy and to integrate this knowledge and skill into their practice.
- Awareness of indigenous knowledge related to science.
- Encouraging education for sustainable development.
- Aligning with the standards and curriculum as defined within each country.
- Providing the opportunity for teachers to participate in research projects that assess the effectiveness of learning in specific settings
- Assessing, evaluating and reflecting on the professional development experience.

Every country treats competence profile development opportunities in different ways. In Portugal, for instance, in order to progress in their career, teachers need to attend a certain number of accredited courses, formally recognized by the Conselho Científico Pedagógico para a Formação Contínua (CCPFC). Whilst in the UK, for instance, attending training events in order to improve their competence profile is not mandatory for teachers (Euan, 2006). In Finland on the other hand all teachers in general education are required to have a master's degree and in-service training is provided by different providers and teachers are required to attend them every year[18].

In many countries, schools are not likely to give free time during school hours for teachers to participate in such events and often teachers refuse to do it in their own spare time. It is of course understandable that educators will make a stand against being obliged to work after hours but, on the other hand, the improvement of their own competence profile and how well they can prepare the students is key for the future of mankind. So motivational mechanisms have to be put in place in order to overcome this problem and strategies need to be designed in order to reach and convince teachers to improve their competence profiles despite the less than favourable environment for this. Much more could be achieved if schools would recognize the importance of supporting the training actions. Schools need to be aware that they need to prepare students for jobs that have not been invented yet (Schleicher, 2018). They will need to be able to work in an interconnected world, in which students understand and appreciate different perspectives and world views, interact successfully and respectfully with others and take responsible action towards sustainability and collective well-being. Teachers need to have the opportunity to be informed about emerging innovative models and opportunities and also to improve their content knowledge. The results of PISA 2015 related to collaborative working was a big surprise. Fewer than 1 in 10 students had succeeded in collaboration skills (Schleicher, 2018). So, it is obvious that a lot needs to be done to boost these critical collaboration skills.

There are important questions that one must ask when preparing educators. What are the obstacles and barriers faced? Some will be addressed in the following chapters, such as lack of training, deficient infrastructure, lack of support from the school community, lack of vision of education authorities, etc. But what about the challenge of bringing big data to the hands of students that are not interested in math and science? Are they ready to understand that artificial intelligence is already in our daily lives and that they need to be in a position beyond simple users of it? Do they really understand the power of a digital world and its scope? The way forward is to bring those ingredients into the hands of students. In this chapter we will present a few examples on how such skills can be deployed and developed, examples that have been around us for many years already (some for more than 25 years) and still not popular enough to reach students at a global scale (Doran, 2013)

As will be presented in Chapter 6, preparing teachers to train other teachers is also very important. This brings a strong sustainability aspect to any training efforts. As presented in (OCDE, 2014a) around 37% or teachers participate in networks where they are trained by their peers. In (Vincent, 2019) it is stated that the share of students taught by teachers who took part in peer learning increased considerably in the last few years.

It is not only training that is necessary to ensure students will end school better prepared for the future. Nations must understand that teachers need to be valued and respected. It is necessary to improve their initial training, to invest in their continuous competence profile development, ensure the profession is respected and trusted. This is discussed at length in an article presented in Science Magazine in 2012 (Burris, 2012).

[18] https://www.oph.fi/english/education_system/teacher_education

Nations must also make their educational system flexible enough to accommodate the use of modern methods, or better saying, since many of these are not new at all, student centred models such as inquiry-based learning, collaborative problem solving, project-based learning, etc. Teachers need to be trained on many different methods and be capable of using the one that is most appropriate for their students.
Teaching is the most important profession in the world. In schools the future of mankind is designed. Nurturing the inner power of each student, giving them confidence and resilience is a very important task. In (Burris, 2012), Finland is highlighted as an example where teachers have a central role in society. A successful teacher is the one always ready to accept changes at a rapid pace, to ensure each student is treated as an individual and making all possible efforts to facilitate learning in various formats if necessary. Not everyone can be a teacher, and this should be acknowledged by the ones in charge of recruiting these professionals. There are some competences that can be learned and some that are innate. Among other characteristics a teacher must be: tolerant; open to questions; creative; resilient; capable of interacting with their students; willing to assume the role of a facilitator; able to create a favourable learning environment for each group of students; able to use different teaching strategies; capable of identifying different student needs; be a good communicator; be capable of collaborating with colleagues. The well-being of a teacher, their sense of self-efficacy, is usually associated with student motivation, a more positive behaviour and longer development in the career with higher levels of retention (Schleicher, 2018). The world needs advanced knowledge workers at a global and general level, not only in some isolated examples.

Teachers are the gatekeepers of our future. In their hands lie the mission of preparing future generations. Innovative technologies are reshaping the way we live and the way we connect with each other. Knowledge management, ICT integration and common strategies for schools across the world are crucial points when rethinking the way, we educate our children. Building bridges between the school today and the school of tomorrow is urgent, and the tools are already available. Here we want to showcase how innovative technologies and the creation of networks of educators can help us design the roadmap for tomorrow (Doran, 2014).

It is widely acknowledged that teachers have to face several organizational problems in schools which is an impediment for the integration of TEL in their practices. These barriers are of various orders, as will be shown in chapter 6, which makes it less likely that innovation will be easily integrated in schools. A strict curriculum, frequently not following technological and scientific development, is also a significant obstacle in the pathway of champion teachers. To add to this, time constraints are also a major inhibitor (Bacigalupo & Cachia, 2011). The existence of support coming from the school or local community is important but the support of a community of peers has even more impact. Several projects follow this strategy (i.e.: eTwining[19], Scientix[20], Galileo Teacher Training Program, to name a few). This model is not new and has been in place for over 25 years in the framework of the programme Global Hands-on Universe (presented in this chapter). In (Bacigalupo & Cachia, 2011) some positive teacher networks impact are presented:

- Enhance the quality of teaching by enabling teachers to expand their capacity in a wide range of dimensions. This aspect is further studied in chapter 6 where the existence of ambassadors (teachers that train their peers) is key to community building and professional development.

[19] https://www.etwinning.net/
[20] http://www.scientix.eu/

- The use of OERs (Open Educational Resources), something that is also presented in this chapter as part of the Open Discovery Space Initiative[21].
- Facilitating sharing of education resources by promoting the use of creative commons licenses and fostering quality control mechanisms. Something that is being largely adopted in the framework of the project Go-Lab also presented in this document.
- Devising long-term sustainability strategies for teacher networks which is at the heart of the 5 pillars for community building presented in chapter 6.

4.1. Global Hands-on Universe – A concrete example and success story

The project was born in the 1990's with the support of the USA's National Science Foundation and Department of Energy. The programme was born with the main objective of involving students in astronomical research projects. Students use research imagery and image processing software developed by Hands-on Universe (HOU) in order to visualize and analyse the data. The project developed several activities to accompany the research projects and invested in teacher training to provide educators with the necessary support (Asbell-Clarke, Pack, Pennypacker, & Toler, 1996). HOU developed a robust curriculum integrating mathematics, science and technology while introducing students to astronomy research. The model developed by HOU to train the teachers was later adopted by GTTP (the Galileo Teacher Training Program). The model was to train an initial cohort of teachers that served as pilots and validators of the programme, the so-called Teacher Resource Agents (TRA). These teachers then support the training of other teachers, supporting the growth of the project. The TRA underwent several rounds of training and continued to support their colleagues. The project surveys and evaluations showed that students were motivated to learn and that they retained scientific and mathematical concepts because they see the direct application of such material. They enjoy using the computer and see it as much more than a word processor. The reader should be reminded that we are talking about a study carried out in 1996.

At the time of HOU project's foundation the creator, Prof. Carl Pennypacker, was working in the Supernova Cosmology Project - the project that in 2011 gave a Nobel prize to Saul Perlmutter for the discovery of the accelerating Universe. Carl was Perlmutter's supervisor at the same time as he was developing the Hands-on Universe Project (Doran, 2014a).

The project had its first prominent success story when two high school students, under the supervision of their teacher Tim Spuck, discover a Supernova (SN1994I)[22]. Melody Spence and Heather Tartara (Figure 27) requested observations of the Whirlpool Galaxy during their investigation of spiral galaxies. A few days later they received a phone call informing them that they had captured the first light of the SN1994I. The students appeared as co-authors on the paper presenting this object to the scientific community.

[21] https://portal.opendiscoveryspace.eu/

[22] http://www.cbat.eps.harvard.edu/iauc/05900/05961.html

Figure 27 Melody Spencer and Heather Tartara, the discoverers of the SN1994I © HANDS-ON UNIVERSE

The second prominent success led to the development of IASC, the asteroid search project presented in chapter 1. It was born in 1998 as an experiment following the discovery of an object from the Kuiper Belt by students from the Northfield Mount Herman School in Massachusetts, as reported by the BBC[23].

The vision introduced by Hands-on Universe, as presented in Chapter 3, was that a cascade effect is necessary in order to achieve sustainability in teacher training initiatives. The teacher training events had an important component - attendees were encouraged to promote further training events. A series of international training events were promoted and only those educators willing to propagate the experience were invited to come. These Pilot Teachers had the mission of spreading the experience to colleagues in their schools/localities. In Portugal over 300 teachers received training on the use of the provided exercises, software and use of robotic telescopes.

4.2. European Hands-on Universe – Researchers in Classroom

In 2004, after reaching several countries around the world the HOU was adopted in Europe by a consortium led by the Pierre et Marie Curie University (France) and received funding by the European Commission. Eight countries in Europe decided to adopt the method and, funded by MINERVA, formed the European Hands-on Universe[24]. NUCLIO was the national coordinator in Portugal. Several resources were produced and data reduction software developed. During the second phase of the project 14 European countries were involved in this initiative. At an international level, at the time of the creation of EU-HOU, there were 20 countries using the HOU approach, the starting point of the Global Hands-on Universe Consortium. Scientific research projects started to be tested in EU-HOU schools, Russia and the USA.

The whole HOU methodology was adopted, curricula localized, and new software developed, Salsa J. A new series of exercises using real imagery was produced introducing innovative research to the hands of European students.

[23] http://news.bbc.co.uk/2/hi/science/nature/221204.stm
[24] http://www.euhou.net/.

The consortium of European Hands-on Universe introduced an important component in the project - the free and open source software Salsa J. By using this software teachers were able to reproduce scientific research experiments and engage their students in real research activities. Furthermore, the teachers participating in the project had the possibility of using robotic telescopes in their classrooms. The partnership was strengthened by the presence of partners representing robotic telescopes, in particular the Faulkes Telescope. These two components enabled the starting of a whole new trend for integration of research in the classroom. In Portugal a series of training sessions started and a strong community of users, still active to this day, started to form. The training sessions focused on the use of the robotic telescopes and data analysis of the retrieved images using Salsa J. Suddenly students had the opportunity to learn STEM subjects while reproducing the discovery of exoplanets, finding the black hole in the centre of our galaxy, determining the distance between galaxies using Cepheid variables, measuring craters in the solar system, etc. Training teachers to use these tools and supporting its implementation in the classroom made it very clear that this was a powerful way to bring science to a new level in schools.

4.2.1. Salsa J

Salsa J stands for – **S**uch **A** **L**ovely **S**oftware for **A**stronomy in **J**ava. It is user-friendly software that originated from open-source software used in Biology named ImageJ. The idea was to enable students to analyse data obtained by some of the most advanced ground and space observatories. Students use professionally obtained images and, by following specific tutorials, are able to reproduce important scientific experiments (Doran et al., 2012). Using robotic telescopes, they can further enhance their experience (as will be presented in chapter 5). The software is multilingual and works on all major operating systems. Students can perform simple tasks such as: measure craters on the Moon, make colour pictures, make movies, track the orbit of Jupiter's Moons, etc (Figure 28).

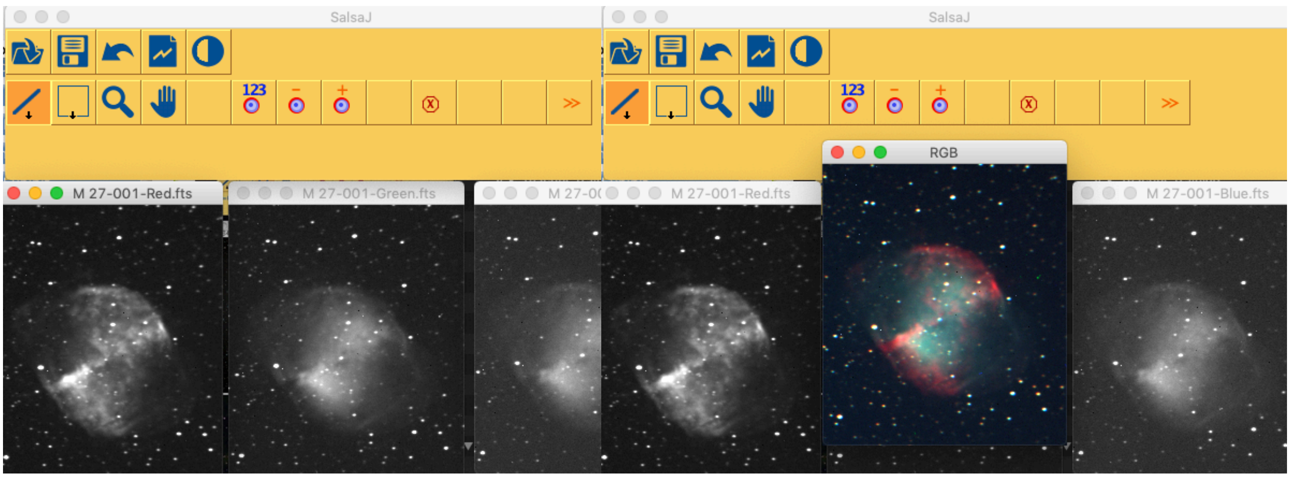


Figure 28 Colour picture of planetary nebula M57

It can also be used to track features on the surface of a planet, to make a plot profile of spots on the surface of the Sun or make surface plots of a group of spots (Figure 29 & Figure 30):

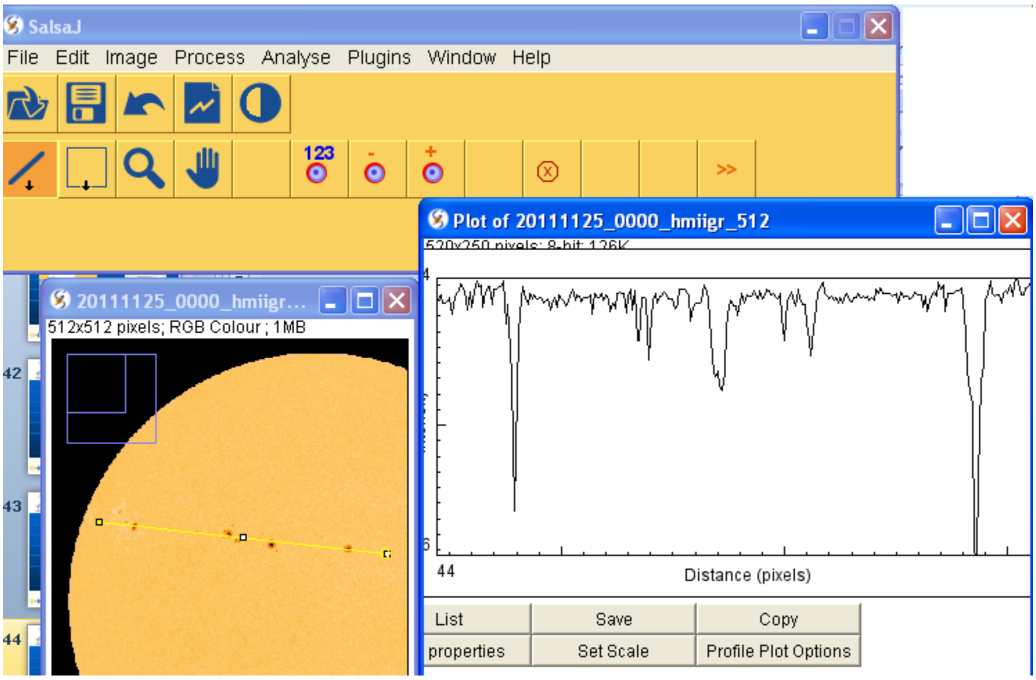


Figure 29 Plot profile done with Salsa J

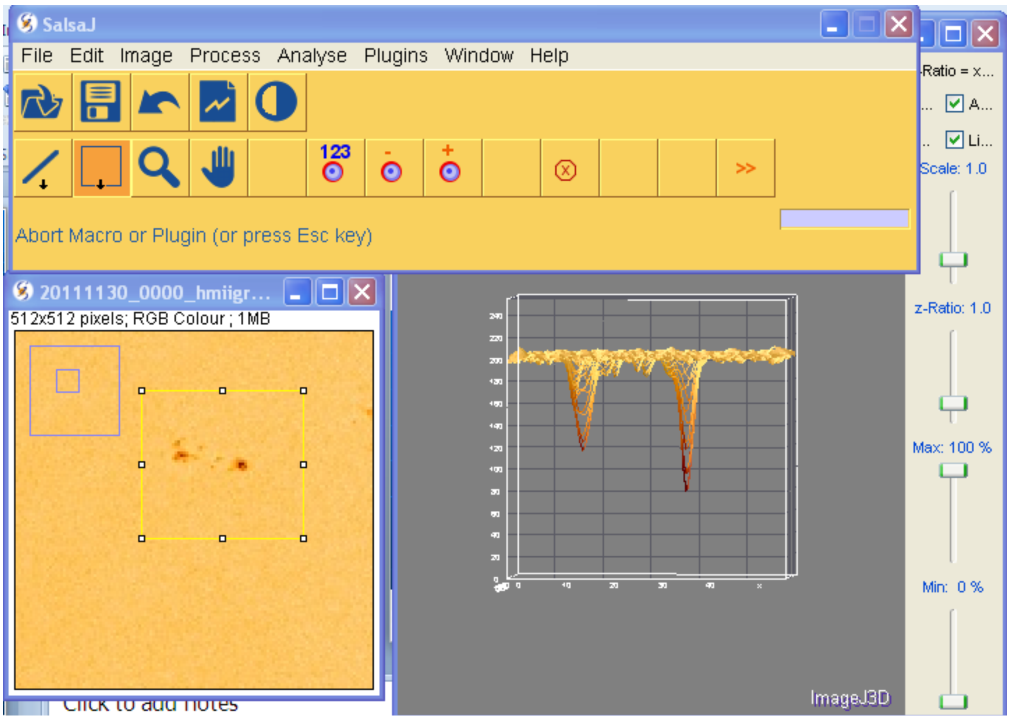


Figure 30 Surface plot done with Salsa J

Students can easily reproduce modern scientific discoveries such as finding the black hole in the centre of our galaxy (Figure 31 & Figure 32). The possibilities of the software are immense and several teachers have been integrating it in their lessons. Even master and bachelor theses have been built around the exploration of Salsa J. One example can be found in chapter 5. The black hole in the centre of our galaxy exercise

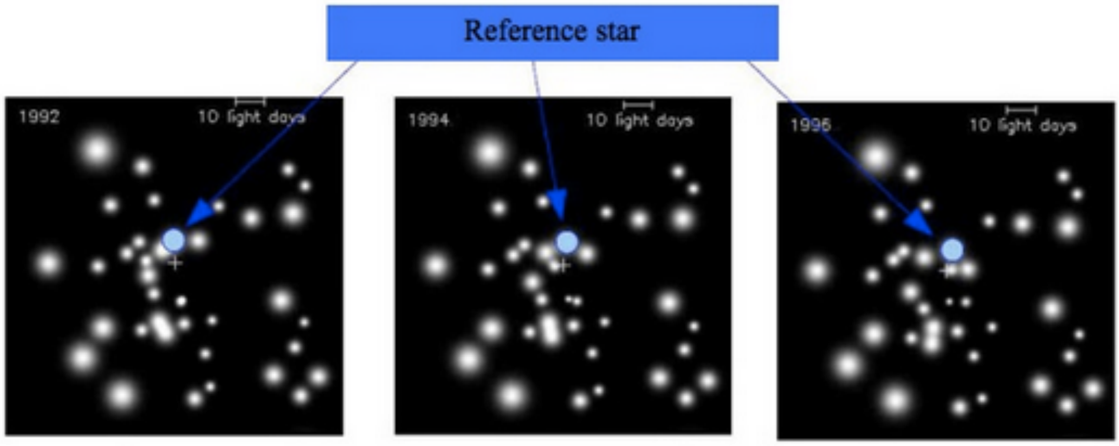


Figure 31 Images of the original discovery of a black hole at the centre of our Galaxy used by students in an exercise with Salsa J

can be found in Appendix X.

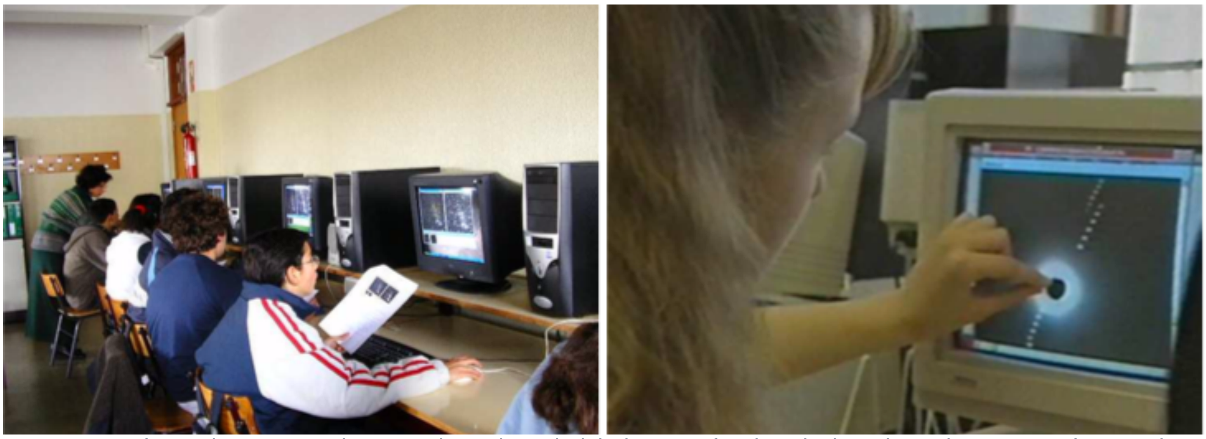


Figure 32 Left- Students at Escola Secundária da Cidadela hunting for the Black Hole at the Centre of our Galaxy, Right - Students in the US studying the motion of Jupiter Moons while learning Kepler Laws © NUCLIO

4.2.2. Faulkes Telescope

Robotic telescopes started to emerge in the 1980s. As presented in the Hands-on Universe example, its possibilities are being studied since the early use of such equipment. In 1994 students started contributing to the discovery of supernovas and in 1998 to the discovery of objects in the Solar System. One would expect its use to be a normal and very common tool in schools nowadays - unfortunately this is far from reality. Nonetheless several initiatives have been implemented since the introduction of EU-HOU in schools across Europe and in particular in Portugal with very inspiring results.

The first research quality telescope made available for education was located at Mt. Wilson Observatory, a 26" telescope. The Hands-on Universe team introduced imagery from several research telescopes located in the USA into classrooms and soon new partners around the globe started to emerge (Gomez & Fitzgerald, 2017). The Faulkes Telescope was built by Dill Faulkes and inaugurated in March 2004. They are two remotely operated research quality telescopes with a 2-meter mirror located in Hawaii and Australia. The operation of the telescopes belongs now to the Las Cumbres Observatory, but the Faulkes Educational Program keeps 30% of the telescope time solely for educational programmes. The equipment is being used in several countries and many discoveries and research projects have been done by students. In (Gomez & Fitzgerald, 2017) we find several nice examples. My personal experience using the Faulkes Telescope was a pure coincidence. A school with time at the telescope had issues with their internet connection. The sky coordinates were shared with me by phone and I diligently inserted them at the telescope command interface. I had no idea that I was observing the Pillars of Creation (Figure 33), ever since my favourite object in the sky:

Figure 33 M16 - Pillars of Creation taken with the Faulkes Telescope © NUCLIO

When this image emerged from the screen of my computer, I couldn't believe my eyes. I was probably the only human being observing this amazing object at that particular time. At that moment I couldn't (and still can't) understand why such possibility wasn't largely being explored in schools across the globe. The limitation on its use is frequently related to lack of self-confidence of users. Constraints are not only related to the use of the equipment but also with the fact that they lack basic knowledge about the topics being presented to them. Many don't feel comfortable with inquiry-based approaches; the lack of time to learn how to use the equipment and the associated content knowledge for each experiment; and their own lack of basic astronomy knowledge are all strong impediments. In chapter 5 a very structured exercise is presented where support and training was provided to teachers alongside the possibility of using the Faulkes Telescope. The result of the study was frustrating since more time was required in order to ensure teachers would build enough trust to actually independently take up the task. Only in one case, where the teachers had a solid background in astronomy, was the project explored to its full extent. Put simply, a treasure for science education is within reach, for free, to any school across the globe. The question is: "How to empower teachers and students to make best use of it?" This is precisely the question being pursued in this research.

4.3. Teacher Training Reaches a Global Scale with the Galileo Teacher Training Program

During the International Year of Astronomy 2009 (IYA2009) the GHOU teacher training model was adopted and transformed into a global project endorsed by the International Astronomical Union as one of the cornerstone projects of the celebration. The project was named Galileo Teacher Training Program (GTTP)[25] and stakeholders from all astronomy education initiatives in the world were invited to join hands. The initiative reached more than 75 nations from 2009 to 2010, creating one of the largest astronomy education networks at a global level (Russo, 2010).

The project remained as a legacy endorsed by UNESCO in the framework of the IYA2009 celebrations. The training initiative at a global level, where modern tools and resources were introduced to educators from all over the world, were determinant for the success and reach of the project. The accreditation of a basic GTTP curricula by several nations and the introduction of fundamental astronomy education resources, freely available on the web were key to the success. Certification and recognition were also an important ingredient.

The nominated ambassadors were invited to conduct teacher training events following certain criteria:

- Address elementary themes and/or concepts of astronomy. To see a list, please visit: http://en.wikibooks.org/wiki/Astronomy
- Use resources that address at least three types of activities such as
  - naked eye or small telescope observations,
  - hands-on activities
  - new technologies
  - robotic telescopes and data mining.

The ambassadors were nominated by the IAU (International Astronomical Union), the promoters of the IYA2009 celebrations. The sustainability of the project relied on this existing network and already well-established network of astronomy and outreach education promoters, the so-called SPOC (IYA2009 Single Point of Contact). The numbers kept growing and over the subsequent years more 100 nations were reached and to date (Dec. 2018) over 50,000 teachers have been reached by the efforts of this network at a global level. The lessons learned during IYA2009 were key to the design of the activities presented hereafter:

- The importance of institutional recognition of the programme by the IAU was a fundamental step;
- Accreditation of a basic GTTP curriculum is key, at a local and international level;
- It is imperative that science education resources, well rated and properly classified, are freely available to schools - funding problems in schools is a global issue;
- Resources need to be adapted to local curricula and translated to local languages. English can be a barrier in many nations (mostly for teachers and educators);
- Promoting activities that foster international cooperation and media interest is crucial for keeping the cultivated initiative alive;

[25] This program was and still is chaired by me with the support of NUCLIO and the Global Hands-on Universe network.

- We must train students for the future as quickly as we can, especially in developing nations were young people are being left behind by the fast-growing digital divide;
- Following up with teachers is very important to ensure they are confident to take the appropriate steps after the training session;
- Create opportunities to implement activities that will attract media attention such as the International Asteroid Search Campaign, Dark Skies Rangers Campaign, etc.;
- Foster cooperation among members of local and global networks. Embrace the possibility of implementing real research activities with the support of the local science community;
- Register every step of the training and implementation journey and share with the school and local community;
- Pre and post evaluation are an important tool to help design appropriate solutions for every nation;
- Keeping education authorities aware of developments and achievements is key to building trustable relationships between them and GTTP promoters.

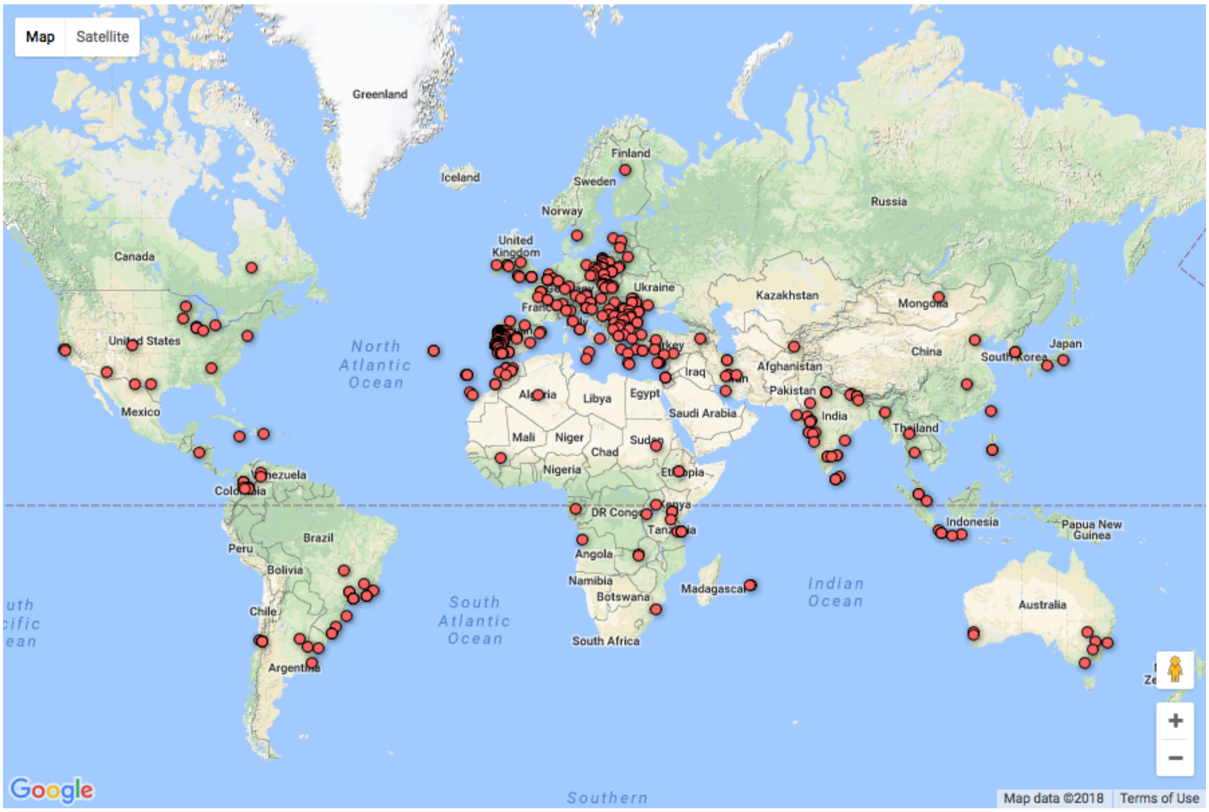


Figure 34 GTTP network at a global level

The network (Figure 34) remains a highly sustainable venture and is still one of the largest teacher training initiatives in astronomy education worldwide.

This exercise allowed the construction of a backbone for a successful teacher training initiative. Explicitly with the following major ingredients as reported in the full report of the International Year of Astronomy 2009 (Russo, 2010)

- The creation of a closely linked global network that will accompany and support teachers after the training sessions;
- The excellence of the network (both in terms of education, science research and access to state-of-the-art facilities);
- The use of real research examples (e.g. robotic telescopes) as tools for teaching science content;
- The use of inquiry-based, self-evolving tutoring methods;
- The use of hands-on activities to teach curriculum content in a "learn by doing" approach;
- The connection between real scientists and schools;
- The active promotion of multicultural dialogue through scientific quests;
- The existence of a certification process that ensures the quality of both trainers and training sessions;
- The construction of a sustainable network of scientist and educators, sharing knowledge, expertise and resources, co-operation globally to build a more scientifically literate society;
- The adaptation and localization of resources to national curricula and, if necessary, to the local language;
- The involvement of the school and local community;
- Do pre and post evaluation to assess the impact of training events on educators and students;
- The network acting as a "professional learning community" where teachers have a sustainable place to learn, reflect and evaluate their students and their own learning with their peer teachers and content experts.

Some key elements, such as continuous support, integration of innovative technologies and hands-on activities in the numerous training events, were integrated in some important projects funded by the European Commission. GTTP became a best practice example of the power of a strong community building initiative and the recognition scheme of teachers participating in the project (Doran, 2014). This organizational structure, methodology and procedures were further explored and validated in the framework of the Go-Lab project as presented in chapter 6.

The whole learning and teaching journeys are filled with bridges that we have to cross: bridges bringing us from our initial training to the real world of work; bridges between information acquired in our learning path and updates happening every day; bridges between technologies we are accustomed to and innovations that are far beyond our comfort zone. Building bridges between the school today and the school of tomorrow is urgent and the tools exist already (Doran, 2014).

Following in the footsteps of GTTP, we are also interested in pursuing the impact of the creation of a sustainable network of educators where trained teachers will train other teachers to become ambassadors for a particular initiative. According to TALIS study (Adesope et al., 2013) this model is an important alternative to traditional teacher professional development programmes, e.g. seminars, workshops and conferences. The study shows that, for their professional development, teachers trust communities of practice where they have the opportunity to share experiences and practices with their peers.

4.4. Discover the Cosmos

The first opportunity to use the experience gained with GTTP appeared in the framework of the project "Discover the Cosmos", an initiative funded by the European Commission under the FP7 programme, represented in Portugal by NUCLIO. The project brought to classrooms the possibility of using several research infrastructures with a selection of over 600 resources that could be used to inspire students and engage them to follow the scientific method in classrooms (Doran, 2013).

A selection of these activities were brought to teachers structured in long term teacher training events. The use of robotic telescopes, data imagery and user friendly software was associated from the start to a strong delivery methodology - inquiry-based learning. The excitement of teachers participating in the training events was clear but still, the implementation in classrooms failed. The main reason continuing to be the lack of self-confidence stemming from a lack of support. In Portugal NUCLIO adopted the model being used by the partners at CERN - the masterclasses. In order to support the implementation of Discover the Cosmos at a national level a series of masterclasses were brought into classrooms all over the country. The masterclasses were structured with different components:

- A presentation about the topic to be explored
- Workshop for teachers and students to present the relevant associated software
- Hands-on activity for students
- Science-café for the local community to share the experience

During these sessions students had the opportunity to prepare and run an observing session using the Faulkes Telescope and process the images taken with the telescope using Salsa J.

By retrieving the Google Analytics of the usage of the Discover the Cosmos Portal we find that Greece and Portugal were the countries with more visitors, and each one spending over 10 minutes per visit to the site. The activities uploaded by NUCLIO and the University of Coimbra were among those collecting more interest from portal users. The evaluation questionnaire presented by the team evaluating the project (Reimers, Pointner, & Huber, 2013) found the following important results:

- Over 76% of teachers participating in the project were physics teachers,
- The majority of students participating in the project were older than 10, with over 82% between 15 to 18 years old,
- <u>Most responders presented low or no experience in IBL (Inquiry Based Learning) although over 92% demonstrated a very high interest in learning,</u>
- <u>45% of teachers attending the training workshops were looking for new methods of teaching in classrooms</u>
- 43% of respondents indicated the desire to use more practical exercises in their daily teaching practice
- Salsa J was among the most popular e-Science application chosen by participants
- The need for translation of resources and tools scored very highly

Clearly the will is there and becomes more and more evident that a large variety of factors are influencing, if not preventing, teachers from introducing changes in the classroom. This aspect is further explored in chapter 6

In Portugal 293 students participated in a special evaluation with the most interesting results presented below:

1. The students were asked if they would like their school to have more activities of this type. 94% answered yes (Figure 35).

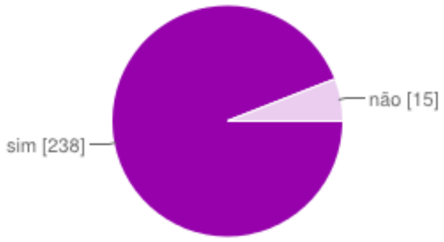


Figure 35 Result, if students like more activities of the presented approach

2. 91% of students were interested in the presented tools and resources (Figure 36).

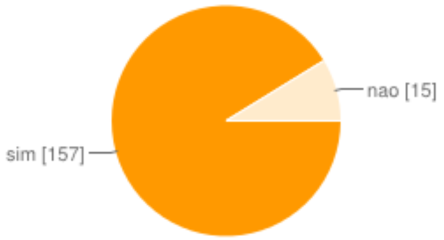


Figure 36 Result, if students were interested in the presented tools and resources

3.) And at least 73% will you use the e-Science tools in their studies (Figure 37).

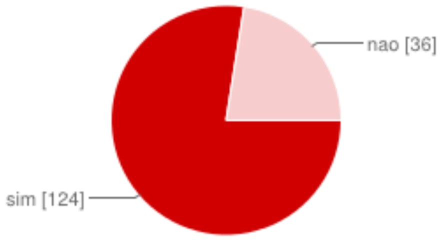


Figure 37 Result, if students will use the e-Science tools in their studies

These results show a very clear picture of the motivational element of using inquiry in the classroom with innovative e-Science tools and applications. A large fraction of students was interested in the presented learning activities and would like to have more of them. Most of them are also eager to use e-Science tools for their studies in the future.

4.4.1. Sun4all

Several important partners were involved in this project, including the Astronomical Observatory of the University of Coimbra with the Sun4all initiative and making available to students its solar spectroheliograms database - over 30,000 images of our Sun taken daily since 1926. The project enables students to work with real solar images, some of them never analysed before (Esperança & Fernandes, 2013). Students are invited to explore several different properties of the Sun by exploring the imagery taken in different wavebands. The project has an associated booklet with a series of activities that can be used by different subject areas including Mathematics, Physics, Biology and ICT; the activities range from simple exploration of the Sun, getting to know its dimensions, understanding prominences, to scientific research such as tracking the solar activity cycle of the Sun and eventually trying to understand its correlation with (or lack of connection to) climate change.

In the framework of the project Discover the Cosmos a national contest was launched in Portugal based on the application, manipulation or reproduction of spectroheliograms obtained during April 2013, with the goal of building an activity achievable in the classroom and presented in the form of a lesson plan.

The excitement of students and teachers enabled the scaling up of the project scope, with schools from all parts of the country being reached during 2012 to 2014.

The project was also part of another European Commission funded project, "Socientize", a citizen science project that was aiming, among other things, to raise awareness about the importance of citizen science, and collect and share best practices and recommendations for the implementation of citizen science projects in Europe. Sun4all was one of the projects chosen to help fulfil the project aims.

Again, the implementation of all these initiatives in schools opened new opportunities: bringing cutting-edge research to schools; promoting the approach between schools and research infrastructures; facilitating the learning of science while doing science; etc. However, although the impact of the implementation of research experiments in classrooms had a huge effect and a network of engaged teachers started to be created, there was no evidence of the possibility of independently replicating the experience. The roadmap to transform teachers from consumers to creators is still missing a few elements.

4.5. Open Discovery Space – A first Community Building approach

A community is a living being that needs nurturing and evolves along the way. Modern communication tools are revolutionizing the way we share knowledge and communicate. Frontiers are becoming invisible and information is slowly making its way towards all corners of the Earth. Social media is fulfilling its developer's vision and making the world a very small place. Socially powered initiatives are a strong side effect of this possibility and in many cases becoming a powerful tool to validate and endorse the quality of its target. Smart, integrated solutions for effective communication, collaboration and exchange of experiences are being built and the demand for them is continually growing (Doran, 2014).

Open Discovery Space (ODS) was a CIP-PSP programme, co-funded by the European Commission, with the aim of creating a very strong community building and resource sharing platform. With 52 partners in 21 European countries, with NUCLIO national coordinator for Portugal, ODS was the largest eLearning project ever launched by the European Commission. The ODS project was created to introduce innovative resource-based teaching and learning practices in European schools, to promote the creation of communities between European school members and to boost the demand for open educational resources among teachers (Peinado et al., 2015). The platform presented a rich repository of OER (Open education resources), tools and resources to tag resources, online community infrastructures, sharing facilities, authoring tools, etc. The vision of this integrated solution was to provide a one-stop-shop for educators where they would find resources, communicate with others, exchange experiences, etc.

The implementation of this project was divided into three main phases: Stimulating the interest of teachers and schools to participate in a large scale scheme to use e-learning resources, the incorporation of innovation in school settings and, finally, accelerating the implementation of innovation (Sotiriou et al., 2016).

In the framework of this project more than 2,000 European schools were clustered around 400 thematic communities and over 12,000 educators reached. The community building process adopted by the project and implemented in Portugal was completely aligned with the GTTP approach. Over 800,000 digital tools and resources were gathered in dedicated online communities - used during the implementation phase where teachers were trained to use and repurpose the material offered in the specific communities.

Over 190 schools are registered in the portal in Portugal and the established network of users was very active (Figure 38).

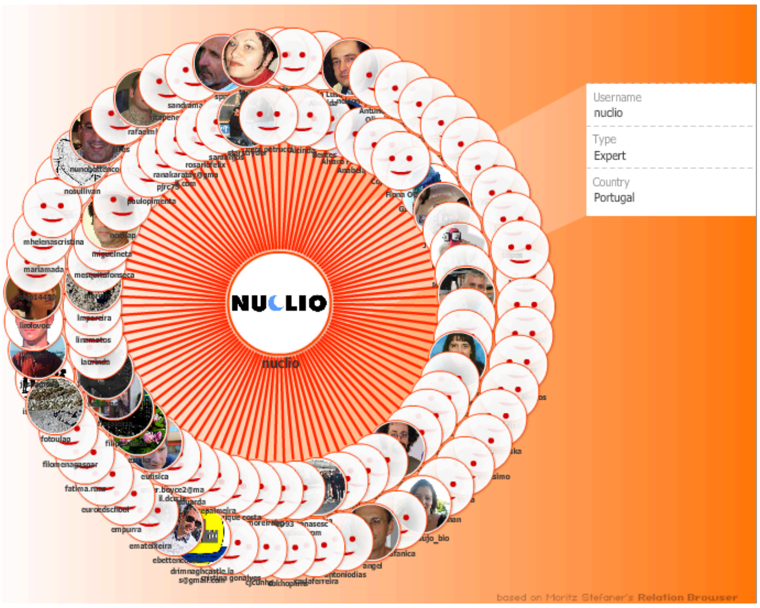


Figure 38 Social Relations of NUCLIO established in the framework of ODS portal

Each member established another cluster of social relations with members of the same community or others. The online communities and the associated activities performed by the national coordinators in order to bring Open Educational Resources (OERs) to schools were key for the uptake of the project vision. OERs are becoming more and more frequent in the educational world, however, teachers often lack the skills to develop activities and often view technology as a tool to support their teaching rather than a tool to produce self-tailored materials. Another severe problem is the time that is necessary to invest in the search for material. So the ODS thematic communities were considered very important and useful not only for finding good resources but also for promoting the possibility of re-use and re-purposing them for personal use (Peinado et al., 2015). In Portugal, ODS was brought to schools through a series of activities to motivate the use of cutting-edge tools and resources for science classrooms. The topic selected was astronomy and its applications.

The goal of ODS in Portugal was to train teachers in the use of relevant materials while engaging their students in real world research within the classroom. The design of the platform required a very important, crucial aspect, to ensure the success of the enterprise: sharing tools and resources; communication among peers and different communities; and creating a strong and sustainable project legacy. One of the successful examples was the community dedicated to the fight against light pollution and the associated programme: "Dark Skies Rangers" (presented next in this document). Over 300 teachers and 5,000 students were reached by this initiative.

ODS was considered the main vehicle for the implementation of the Open Up Education initiative (Sotiriou, 2014). The report states clearly that communities of practitioners at EU level have proven to be solid solutions for exchanging good practices and for peer support, as shown by ODS (EC, 2013). The Opening up Education initiative launched in 2013 set an agenda for stimulating high quality innovative ways of learning and teaching through new technologies and digital content. The vision is the support of institutions, teachers and learning in the acquisition of digital skills, making educational resources available, connecting classrooms and mobilizing stakeholders.

In 2015 a new report on Open Educational Resources states that OERs are becoming a major phenomenon in education across OECD countries (Orr, Rimini, & Damme, 2015) and are acting as a catalyst for social innovation, facilitating interactions between teachers, learning and knowledge. OERs can extend the lifetime of specific resources enabling global distribution, adaptation and localization for specific user's needs. It may be used to foster the use of new forms of learning and teacher's professional development, holds the potential of improvement via user generated versions, and may act as a bridge to the literacy divide. Making OERs available in repositories that have the potential to reach a large number of users, however, doesn't mean that it will act as such. The presence of a community of users and supporters is key for the successful use of OERs.

Still, it should be noted that not all OERs have the necessary quality. Being user generated requires time for the improvement and skills of potential users to be able to re-use and re-purpose what is made available to them. In the Portuguese experience a worrying lack of digital skills was evident in most training events. Teachers have difficulty in performing basic tasks on computers and are still far from having basic ICT skills (UNESCO, 2011).

Over 400 schools were actively engaged in ODS activities in Portugal. The strategy we used was to cluster them around thematic communities and to empower them through community building events: teacher training and school workshops (Figure 39), online Masterclasses (Figure 40) where students had the opportunity to engage with scientists and students from other schools in different countries. We also started a large-scale strategy of having peers supporting their colleagues. Spontaneous communities created by teachers also started to emerge (Figure 41).

Figure 39 Teachers training other teachers

Figure 40 Portuguese students communicating with a school in Ireland and with ESA scientists during the wake-up Rosetta day © NUCLIO

Several thematic communities presented a high number of users, which usually also involved face-to-face gatherings (Figure 42). One of the communities for ODS was one devoted to the fight against Light Pollution. This was part of the preparation of teachers to participate in the Dark Skies Rangers programme. The most important results are presented below.

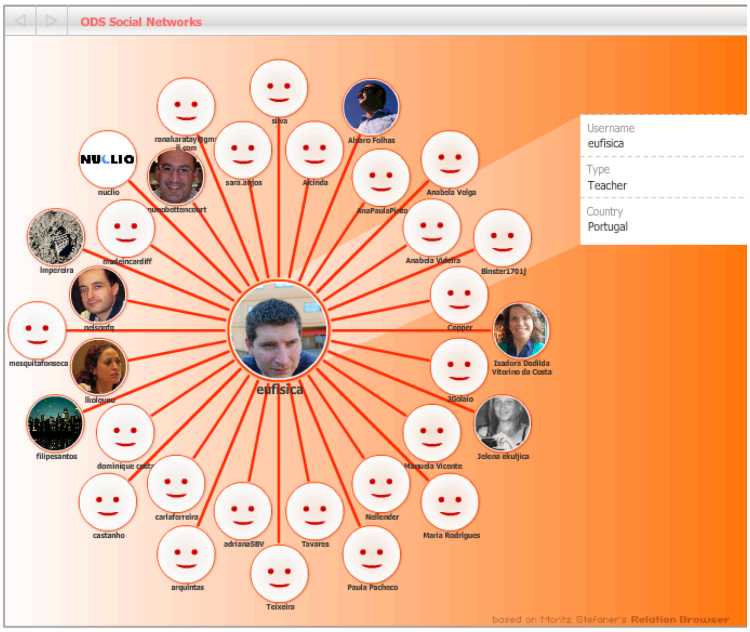


Figure 41 Example of a community established by one of the members of NUCLIO communities

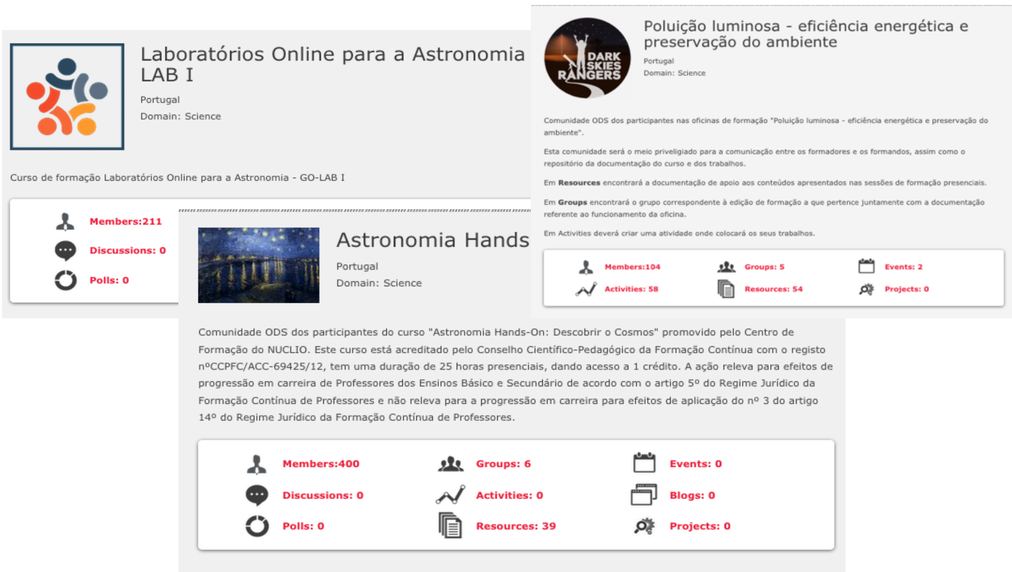


Figure 42 Some of the Portuguese communities with more members

4.5.1. DSR

Dark Skies Rangers – A programme aiming to create awareness about the growing problem of light pollution. In this project teachers were trained in the use of homemade instruments that could help spark students' interest in the topic and engage them in local project development. This project benefited most from the ODS platform and its innovation model. It fostered inter-school collaboration and the use of content rich digital tools. Students had to first perform a light audit on a chosen street, then produce a report on their findings and, finally, propose solutions to change the street/buildings illumination. They should then proceed to design a mock-up of a well illuminated street, in collaboration with other teachers and students, and present their findings to the mayor of their municipality. The project closely followed the outline of the ODS innovation model and, together with the national community, explored the different components of the platform, thus greatly contributing to its improvement. Over 1,000 students have been involved in the project so far.

Dark Skies Rangers (DSR) is a joint collaboration between the National Optical Astronomy Observatory of the USA (NOAO) and the Galileo Teacher Training Program (GTTP) (Doran et al, 2012). In Portugal, in the framework of ODS, a pilot initiative was implemented in the municipalities of Cascais and Torres Novas to test the adaptability of the tools and resources in classroom, the receptivity of the communities and impact in the schools. In Cascais the programme started with 50 students analysing the light pollution in the streets surrounding their schools. During the school year of 2012/2013 ten more schools integrated the programme and the objective was to have a good map of the light pollution in the major areas of town. In Torres Novas the programme was adopted by 93 students and 10 teachers in a cooperative effort. Students from 7th to 12th grade were involved in a wide range of activities. This project received a "Science in School" award from the Portuguese Foundation Ilídio Pinho. Teachers trained in the framework of the project were encouraged to work in collaboration with their colleagues, to use the repository of tools and resources made available to them in the ODS community. They were further encouraged to collaborate with other members of the school community and try to engage other stakeholders of their local community. The implementation work was done mostly with 7th graders, where astronomy is part of the curricula. The impact of the whole strategy was very encouraging and several best practice examples emerged from this experience.

Caso Camarate (Camarate's case) – This project was done in a school that was integrated in a programme called TEIP (Educational territories for priority intervention), where one of the goals was to mobilize stakeholders in the local community and engage them in priority work for the benefit of the community. The school is located near a highway and airport infrastructure. The project emerged with the aim of creating awareness for the problem of light pollution, to promote a light audit related to the illumination of Camarate and discuss the impact of light pollution in living beings. The project was conducted in the school year of 2015/2016. Students participating in the light pollution audit performed several research activities related to the impact of light pollution in the fauna and flora, participating in workshops and sharing their research with the whole school community (Nunes & Dourado, 2017) (Figure 43).

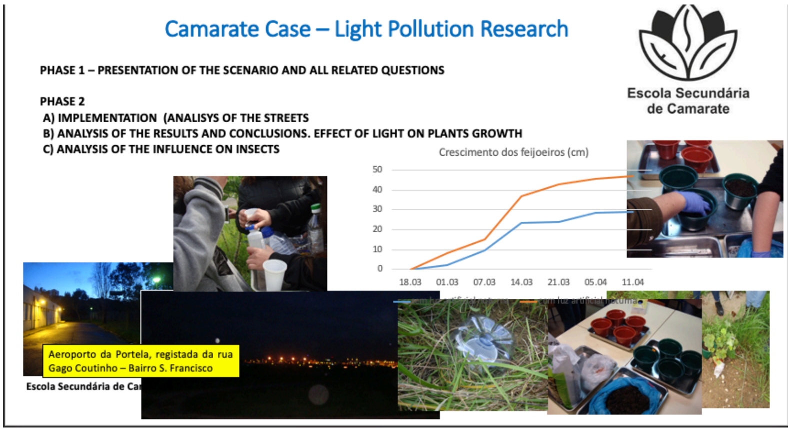


Figure 43 Some results of the research performed by the students

Other examples of successful implementation of the project were the Dark Skies Rangers project in Escola Básica de Alapraia where students developed a whole experience to test the different types of illumination (Figure 44), or the case of Escola Básica de Amarante where students made a full analysis of the expenditures of the municipality on street illumination (Figure 45).

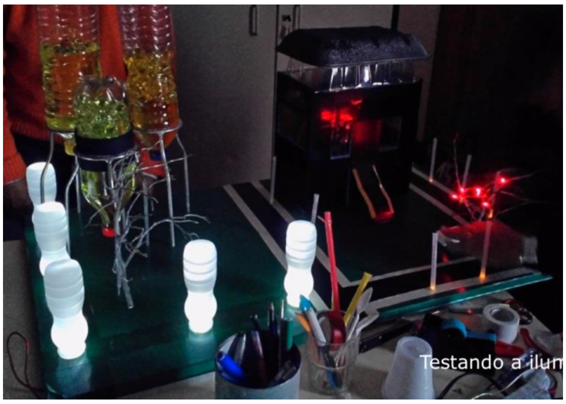


Figure 44 DSR in Escola Alapraia

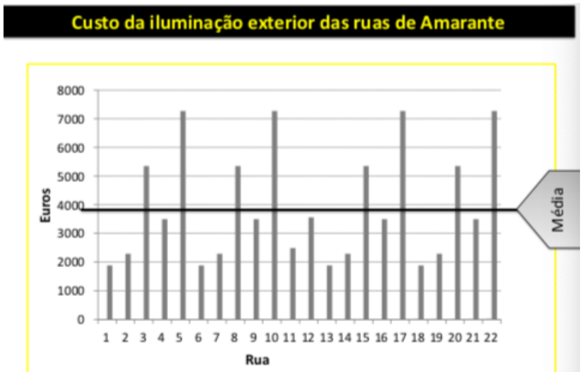


Figure 45 Energy waste project by Escola Básica de Amarante

In Vila Real, a district in the North of Portugal, a 7-year-old boy delivered a DVD with a video produce by him asking the mayor to change the illumination of the streets in Vila Real. In his words:

> "Mr. President, I want to ask you to please replace these streetlights with others, covered above and on the sides, so that we can better illuminate the streets and still save some money. When I grow up I want to be a poet and poets need the bright stars and the romantic Moon to get inspired."

As a consequence of this video the mayor requested a revision of the illumination strategy at the municipality and the subsequent budget for their replacement. At the present moment (February 2018) the streetlights are being replaced by eco-friendly fully shielded ones (Figure 46).

Figure 46 Mayor of Vila Real delivering a DSR certificate – 2014 © NUCLIO

These cases were strong validators of the 5 pillars of community building - engagement, training, support, recognition and community (presented later in this document).

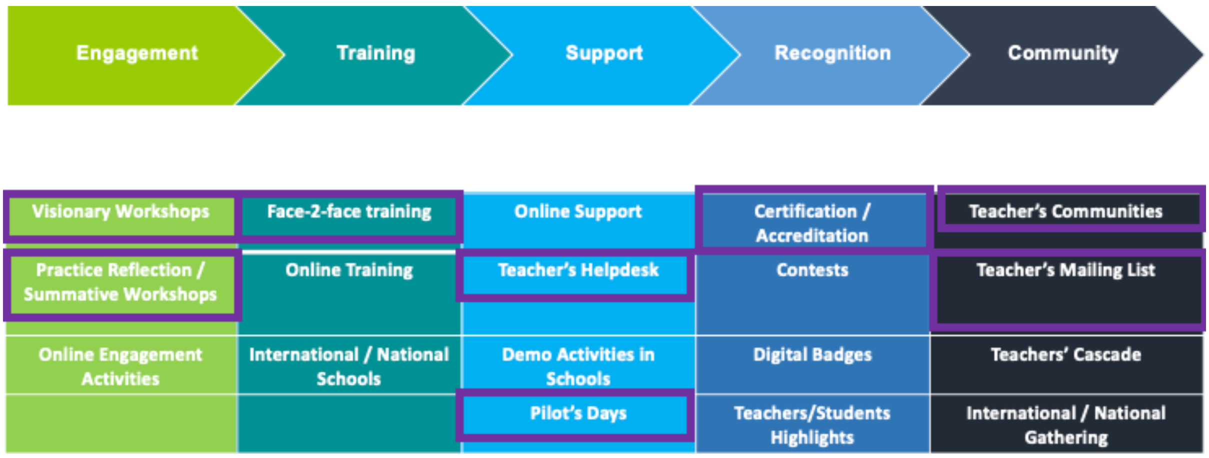


Figure 47 Community building steps for the Camarate's case

4.6. Inspiring Science Education (ISE)

The project "Inspiring Science Education" (ISE), co-funded by the European Commission in the framework of the CIP-ICT-PSP programme had, as a main objective, to encourage the use of eLearning tools for promoting inquiry-based learning across European schools. The project was implemented in 14 countries, coordinated in Portugal by NUCLIO, and successfully reached over 10,000 teachers making available over 300 thematic communities and 173 exemplary IBL resources ("Demonstrators") (Figure 48).

The main aim of the project was to make available to science teachers a tool to design, develop and organize their resources using the IBL methodology. The project made a very rich collection of tools and resources available to the teachers. In the repository educators could find: links to remote and virtual labs; analysis tools; advanced technological applications; educational repositories and portal. Each tool was completely categorized using metadata (Doran & Kypriotis, 2014b) containing: general information, a pedagogical section and a technical section. They were also categorized by the Big Ideas of Science (presented later in this chapter) and age group. Finally, each resource had the information related to its usage and reproduction licence type. A teacher's manual was produced with further information and cross connection of the big ideas, the tools and applications in our daily lives. The full description closely followed the model adopted by the Next Generation Standards[26]. The whole methodology along with a detailed description on how to upload resources, create metadata and create scenarios was prepared and made available to the teachers (Stylianidou et al., 2015).

The project uses the basic 5-phases cycle as presented in (Rutten et al., 2015): Orienting and asking questions; Hypothesis generation and design; Planning and investigation; Analysis and Interpretation; Conclusion and Evaluation. The technical infrastructure was implemented in the ISE authoring tool using these phases. Several ISE scenarios were created following this structure. The ones created by the partners (experts in different fields) were called Demonstrators and functioned as inspiration for teachers to follow the model.

[26]https://www.nextgenscience.org/

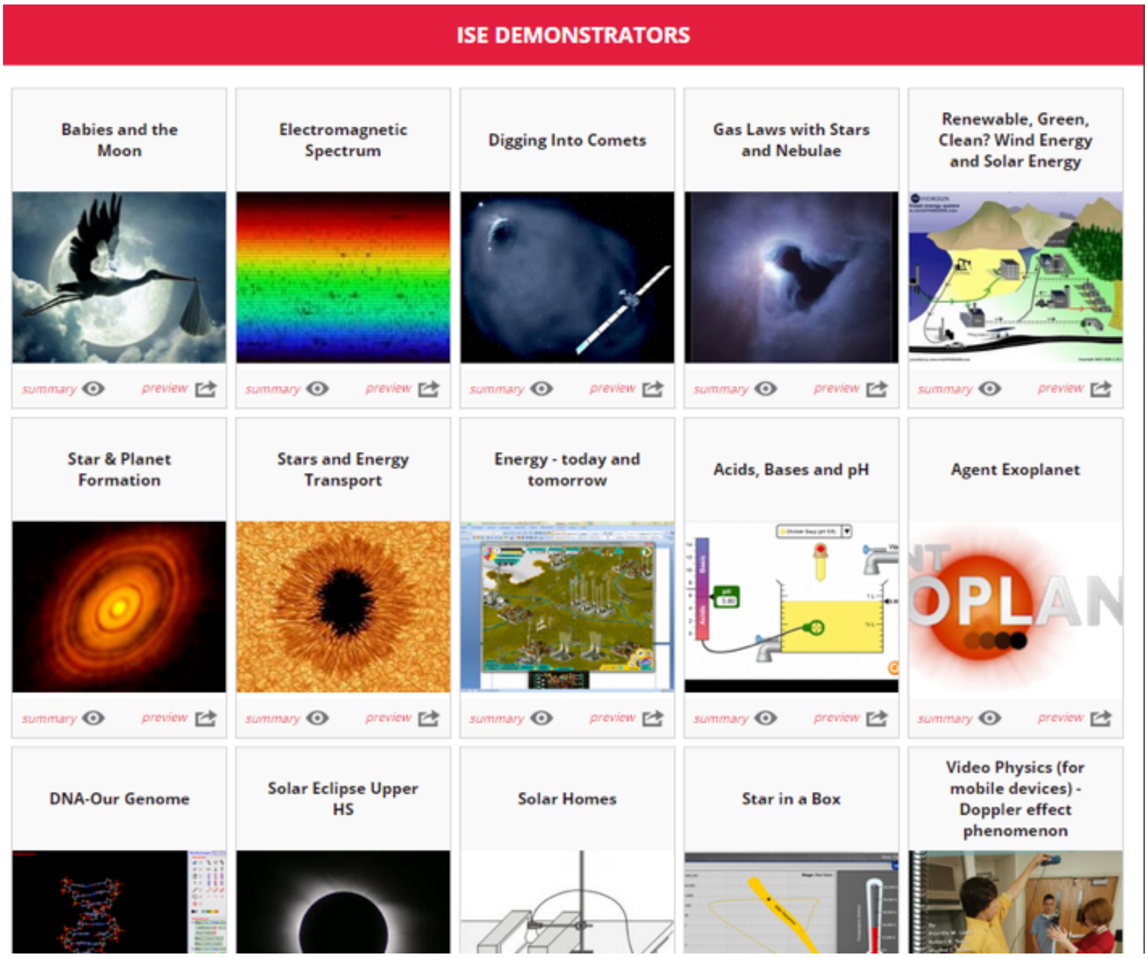


Figure 48 Example of ISE demonstrators

The project also followed a strategy to promote interdisciplinary learning - the integration of the big ideas of science - a concept initiated by (Harlen & Bell, 2010) that is the basis for the science content of the US Next Generation Standards. The main idea is to categorize the tools and resources according to the big idea they address rather than the subject domain. They were slightly adapted in order to fit the ISE purposes and audiences (Figure 49).

1. **All material in the Universe is made of very small particles. Light in all different wavelengths permeates the Universe.**
2. **Objects can affect other objects at a distance.**
3. **Changing the movement of an object requires a net force to be acting on it.**
4. **The total amount of energy in the Universe is always the same but energy can be transformed when things change or are made to happen.**
5. **The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate.**
6. **The solar system is a very small part of one of millions of galaxies in the Universe.**
7. **Organisms are organised on a cellular basis.**
8. **Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms.**

Figure 49 The Big Ideas of Science

Teachers could search for material on specific domains, find a selection of e-learning tools that could enrich their practice and find exemplary scenarios where they could inspire themselves or simple copy and repurpose existing ideas. They could use the Big Ideas of Science to easily find the means to collaborate with their colleagues from other subject domains or other grade levels. The whole infrastructure of the project was a very good facilitator of horizontal and vertical articulation, and collaboration among educators.

Each demonstrator had the possibility of producing a series of questions - general ones and a series that tried to evaluate the problem-solving skills of the students for each specific phase of inquiry. Each phase, with the exception of the conclusion, had a series of questions trying to validate the acquisition of a key competence for that particular phase. All demonstrators were reviewed internally and the whole team had a crash course on how to prepare problem-solving questions. Among the partners of the consortium we had an expert in such questions. Teachers could evaluate the performance of their students compared to the average of the countries using the same demonstrators and to the OECD (PISA 2012 results). Students also had the possibility to see their performance (Figure 50).

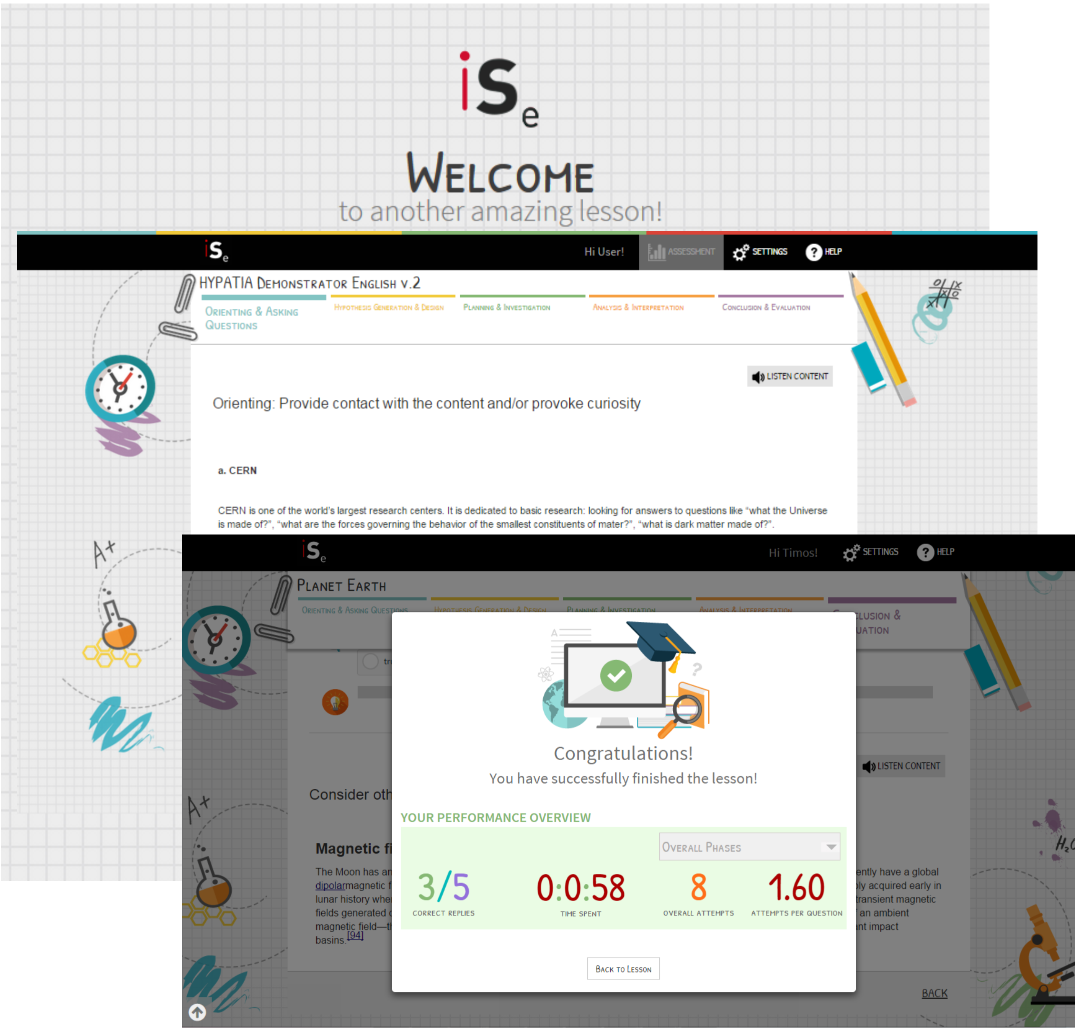


Figure 50 Example of interface for students

One of the tools available within the project was a support tool for the development of educator's inquiry skills, the SIMAULA[27].

In Portugal over 300 teachers received training (Figure 51) to create and/or use scenarios related to astronomy. Very good ideas emerged but to most of the participants it was the first encounter with IBL. Their scenarios in general were not completely IBL but more a first trial to migrate from the traditional teacher-centred model to a digital platform where the student had control over their work. The teachers' confidence on their own scenarios was very low and as a result not many were implemented. So, we decided to take a different approach and launch a contest motivating teachers to implement specific scenarios with their students. We also took a tour across the country bringing workshops to schools. The results were very encouraging, and students really appreciated the possibility of engaging with the platform and the new model for learning. The demo activity was conducted in 10 schools in 5 different locations involving around 20 teachers and 300 students.

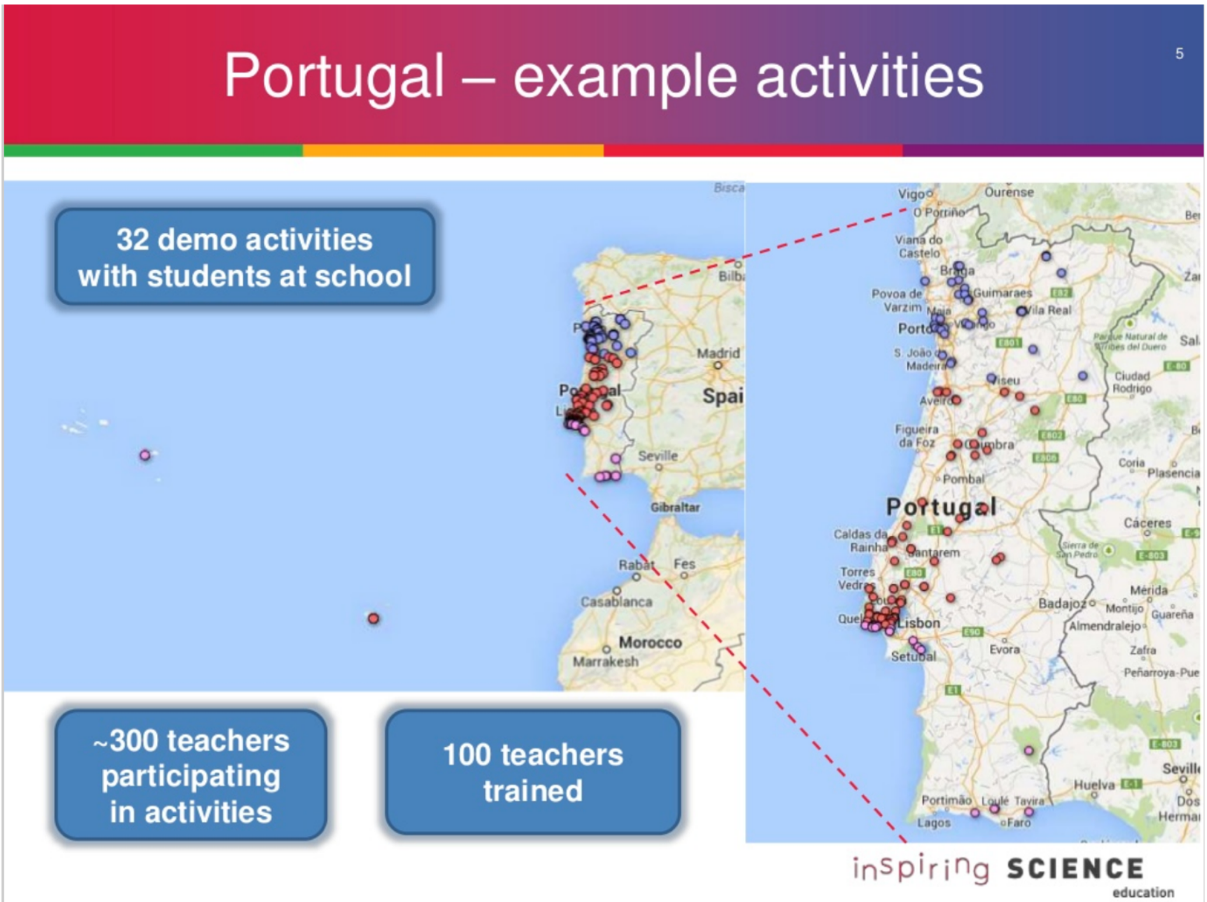


Figure 51 Teachers trained and demo activities in Portugal © NUCLIO

[27] https://portal.opendiscoveryspace.eu/en/tr-activity/simaula-educational-game-environment-673496

Figure 52 Students participating in the ISE workshops © NUCLIO

In total over 11,000 students participated in the implementation of the demonstrators, taking on average 1h:20min to perform the required activities. From these, ~70% of the students completed the problem solving questions (Amany Annaggar, 2016). Using the system analytics, we could analyse the performance of the students while subject to an inquiry activity. More specifically one of the activities produced by us: "Babies and the Moon" (Figure 53).

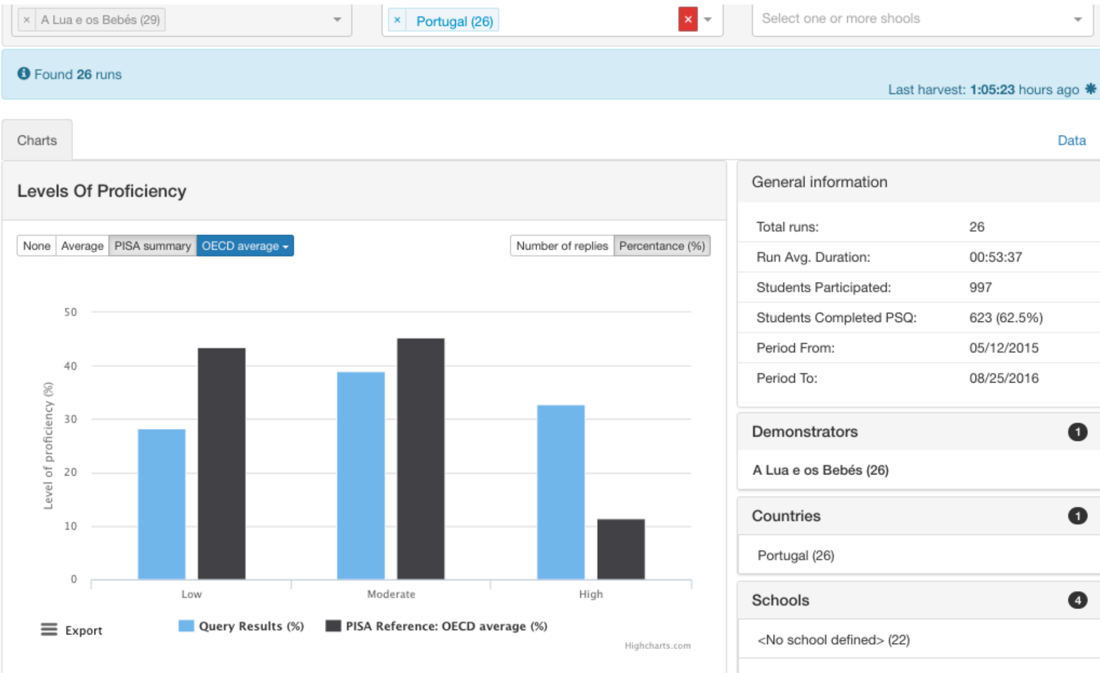


Figure 53 Proficiency profile of Portuguese students as compared to PISA summary

According to the information retrieved by the system students had very good results in terms of their problem-solving competences. The image below shows the average time students spent in each demonstrator. This represents the commitment of the students to their tasks. Some demonstrators required more time from the students (Figure 54). It also shows that it is possible to do an inquiry exercise within the time frame of 90 minutes (on average). In (Figure 55) we see the average time comparison per country.

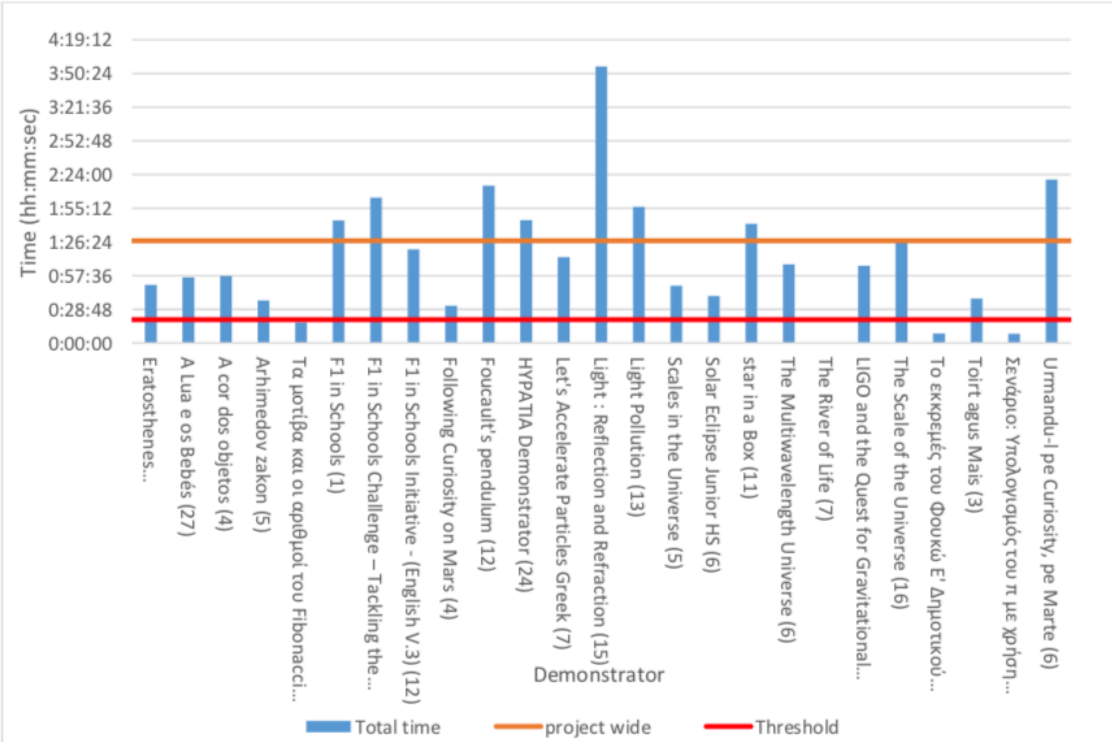


Figure 54 Average time duration in all phases per Demonstrators. The Threshold is the minimum time accepted as being equivalent to an implementation (Amany Annaggar, 2016). Only demonstrators with over 100 students were analysed.

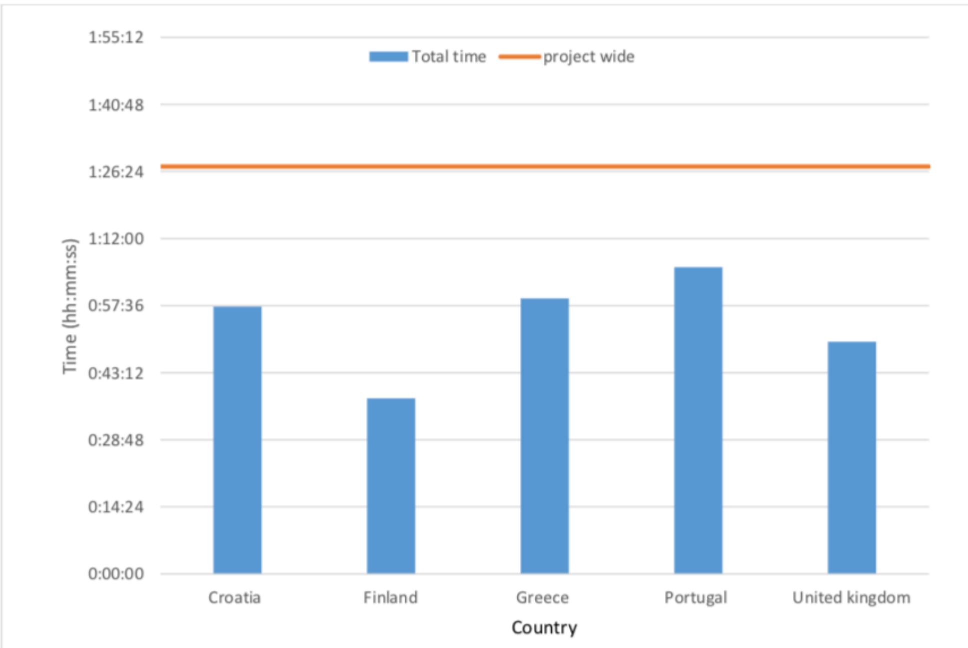


Figure 55 Time spent on average across the demonstrators per country (Amany Annaggar, 2016)

A study performed after the implementation of the scenarios collected very enthusiastic results from teachers where they stated that they had a positive or highly positive effect on student learning with the inquiry cycle. They also stated that students were able to use the scenarios adequately (Amany Annaggar, 2016).

4.7. How to organize an effective teacher training

There are different strategies that one can use while trying to engage and train teachers. The first important step is to decide if the training is just a dissemination event, where the product is being presented to the audience, or if the promoter wants to have an impact on the professional development of the participants (Gaible & Burns, 2014). Although we call our events, presented in this document, teacher training, we are indeed investing in the professional development of the participants. In order to ensure effectiveness of our courses we ensure basic ingredients are in place, aligned with the vision presented in (Gaible & Burns, 2014):

- Ensure engagement of participants and try to make them feel as comfortable as possible with the trainers and challenges being presented in the specific action,
- Understand their starting point in terms of pedagogy, technology, content, etc.,
- We offer multiple opportunities for the same teacher to participate in training events, for the same or different topics.
- We offer long term support - our gatherings with teachers are never foreseen to be a one-off occasion.
- We put participants at centre stage and use the same methodology we are training them to use.
- We invest in the cascade model, where one teacher will train other colleagues who, in turn, will train others. This ensures reach and sustainability of the project.

It is very important to remember when introducing innovative models, in particular those requiring the use of cutting-edge technology, that through the whole process we are asking teachers to step way out of their comfort zones. The same applies to students, who are highly accustomed to mechanized exercises where the answers are always in the last part of the book. This is, of course, not only the challenge faced by teachers - in most societies' students are required to perform well in national exams on which their academic future largely depends. We have also to take into consideration that the participation of a teacher, and their willingness to promote innovation in their teaching, doesn't always reflect the vision of their colleagues and often might not be aligned with the vision of the school overall. Creating a strong support network of educators, as mentioned previously and as further explored in the remaining chapters, is key of the success and sustainability of any project.

The impact of International networks of educators such as the Global Hands-on Universe, the Galileo Teacher Training Program and others is very important. The multiple face-to-face events are a very rich opportunity for teachers to connect with other realities and other cultures. In partnership with the European Science Education Academy we have been regularly promoting a series of Summer Schools. Since 2010 over 2,000 teachers had the opportunity to participate in international training events in the framework of "Discover the Cosmos", "Open Discovery Space", "Inspiring Science Education", "Go-Lab" and many other projects. The excitement and enthusiasm of the participants is very rewarding, and the effect is long lasting. This is not part of the work presented in the document, but it is worth mentioning that several new collaborations emerged from these events and many ambassadors of the different projects are replicating many times the registered numbers.

The vision that science literacy has to be facilitated with the support of several stakeholders, among them the scientists producing new science themselves, has already been described in this document. However, having prepreparedexercises ready to use might not suffice when it comes to the self-confidence of an educator. Migrating from the expositive model towards a student-centred model, as has been presented in the various projects above, is already a big leap of faith and trust. It requires a strong support mechanism that is present at all times. If the intention is to go a bit further and try to explore a model that introduces more degrees of freedom to educators and opens further possibilities to students, the results might not be what one expects. As a result of our multiple training events and success stories of the participation of the Portuguese teachers in several projects, we have been asked to produce a manual describing the methodology on how to train teachers. The whole model assumes, as a basis, a few important things (Klaus Fahle, 2008):

- Start the training with a brief introduction of everyone involved and with a nice ice-breaking activity, the more comfortable the participants feel with each other the more likely they are to participate actively in the training.
- Trainers and trainees are professionals with equal levels of knowledge in their own fields - the training opportunity is a sharing of best practices and experiences. Be open to learn from the participants as well.
- Ensure there is enough space in the training for the participants to take the stage whenever they feel they have something to share with the remainder of the group, including the trainers.
- Ensure that the specific needs of your audience are met. As with students in a classroom, everyone has special needs. Meet each participant in their comfort zone.
- If you need to introduce components using the expositive way, make sure a series of hands-on activities are mixed in-between the expositive moments,
- Whenever possible try to accredit the course with the local education authorities - this might be very important, in particular when accredited courses are a requirement for the progression of your participant's careers.
- Recognize the participation of the teachers by delivering a nice attendance certificate with the signature of the organizers of the course and any other relevant endorsements you might need. Teachers are usually very proud to see their achievements in the form of a meaningful certificate.
- Introduce a coffee break or a meal every 2 hours. Ensure that you have something for your participants to eat and drink on demand. Remember, our brain is an energy killer. If you have the necessary funding offer this and other goodies, who doesn't like it?
- Ensure the environment where the training is taking place is comfortable and collaboration friendly.
- Provide participants with enough time to meet each other and to talk to each other.
- Include as many energizers as necessary, ask your participants to bring their own ideas, they are very good to keep the morale of the team high.
- Don't forget to evaluate the course and give the floor to the participants to express their sincere views of the training course and its value to them. Make sure the feedback can be done in an anonymous way.
- Ask your participants permission to take their pictures and to use their emails to send further information.

- Before finishing the training make sure they have your contact or that of a member of the team that can provide future support.

These are only a few of the recommendations that are integrated in the document produced in the framework of the Go-Lab project (chapter 6). The full document can be found in (Appendix VII).

We have invited a few teachers, that participated in the many training events presented in this document, to take a survey to measure the impact sometime after they have been trained, and some interesting results are presented below:

- In total 97 participants replied to the survey (67 from Portugal, 30 from other countries).
- Most of the respondents have participated in training events with a duration of 4 to 6 days.
- **99%** of the professionals felt that the training helped them to improve their competence profile and over **90%** consider that the topics were relevant for their lessons. Some of the explanations were very encouraging:
    - Because they were related to competences.
    - The training programme enabled the planning. design and development of new kinds of activities that hadn't been performed with the students.
    - Examples and methodology were innovative and engaging.
    - Hands-on Activities.
    - I learned how to use new tools.
    - Useful for the new curriculum autonomy in Portuguese schools.
    - It made me reflect on some classroom practices.
    - Getting to know other teachers from other schools.
    - Helped me reflect about my practices and how to engage my students in their own learning.
    - Continuous involvement of the students in practical work.
    - Interdisciplinarity and vertical articulation
    - It was the starting point for the change in my methodologies for teaching/leaning.
    - Learning beyond the curricula.
    - I changed the way I introduce scientific concepts.
    - A lot of tips and suggestions to build new experimental activities.
    - Changed my way of thinking.
- Over **80%** of respondents stated that they have used what they learned in classrooms.
- When asked about the most important part of their learning in the courses some of the answers were very positive towards our main aims for the training:
    - Practical component (mentioned by many teachers).
    - Very good guidance.
    - The multidisciplinary aspect of Astronomy.
    - How to communicate difficult topics.
    - Learning new teaching methods.
    - Discovering new resources and being accompanied into this discovery. It made me able to go further on my own after the training. Was empowering. I really appreciate that.
    - To meet teachers with a positive attitude, space enthusiasts willing to share their expertise.

    - The sense of collaboration, and the cultural approval that was strongly promoted.
    - What is the main role of the teachers and how they should teach their students?
    - Learning from researchers, science communicators, colleagues.
- When asked about what changes they have introduced to their teaching practice as a consequence of the training:
    - Design and implement more practical class topics instead of just purely theoretical.
    - I enrolled in more teacher training, webinar, eTwinning projects.
    - Started using more hands-on activities.
    - Create class materials more easily.
    - New and fresh ideas in my classroom.
    - I try to ask more questions, to put them to work together more often, to find answer to the questions themselves as often as possible.
    - My classes are now closer to the interest of the students.
    - I work in an interdisciplinary way.
    - Less expositive lessons.
    - Being able to reach students more profoundly, for instance on the theme of light pollution.
    - Student-centred teaching.
    - I give more time to my students to reflect on their work.
    - My practice changed completely. My lessons are no longer expositive.
    - I am more open to the real needs of students and to their environment so I can motivate them to learn.
    - My lessons are now more dynamic and attractive when I address topics that I learned during the training.
    - The assessment of inquiry lessons.
    - Better collaborative work.
    - Now I can use a lot of web tools.
    - I use more practical examples.
- We also asked the teachers what was, in their view, the impact the training had on their students as a result of changes in their teaching practices. These are some of the answers presented:
    - The interest of the students has increased.
    - The students developed greater interest in researching and probing new topics in the field.
    - Students became more citizens of the world.
    - Children participated in more projects, collaborated with other countries, travelled with Erasmus and the mathematics I teach became more applicable in real life situations to them.
    - Big smiles, better understanding, fun, engagement, personal ideas and experiments.
    - They got to exchange experiences with students in other schools around Greece and Europe.
    - They became motivated in STEM and showed more interest.
    - They have to think and work a bit more to get the knowledge, to find the solution to the problems. They have more individual and group activities.
    - Students appeared more committed, curious and willing to deepen the proposed topics.
    - They learn better.

  - Better prepared for national examinations.
  - Inquiry helped structure their thoughts.
  - Students are more enthusiastic, but misbehaviour episodes are more frequent, they have some difficulty still in self-regulation.
  - Deeper learning about the topic.
  - They understand better, want to participate and do so with more motivation.

- Over **80%** kept in touch with colleagues that participated in the same training.
- Related to their opinion on what was the most important characteristic of a training session to allow the implementation of new knowledge in the classroom:
  - Being led by individuals that are enthusiastic and motivating.
  - Meeting colleagues who have knowledge and experience.
  - Practical training.
  - Giving sufficient time for participants to develop materials targeted to their students.
  - The possibility to experience and work on the materials during the training course.
  - Connection between the content presented in the course and the curricula of the subject being taught by the participants.
  - Exchange of practices among schools.
  - Sharing materials.
  - Building strategies together with colleagues.
  - Concrete examples that are easily transferable to class and concrete links to open, real world projects.
  - Awareness that cooperation can help us a lot and that with today's communication the world can be small.

From the answers to this survey it is clear that teachers are eager to find courses promoting the use of innovative tools and methodologies. In every training we sense that teachers are also unmotivated to continue always using the same methodology. They are eager for change and innovation. When preparing educators to introduce innovation in the classroom we have to be the first to set the example. With this in mind, we try to introduce a lot of hands-on activities for participants and to put them centre stage - precisely as we want them to do with their students. It is clear from these answers that the model had a positive effect. Teacher appreciate the learning of models that provide more collaboration, the use of practical examples, interdisciplinary, etc.

We also see that according to their perception the impact on students was positive and we can even find statements reporting that students were better prepared for national examinations. Teachers appreciate trainers that are enthusiastic about what they are sharing and the opportunity to collaborate with other colleagues.

The participants of this survey were not only from the training courses related to the projects presented above, but also to those presented in the following chapters. However, the essence of a successful teacher training event was already in place at the stages presented so far.

In this chapter I presented a series of projects that had great impact on the teacher communities and students they reached - but the important lesson to be learned is that it is all about people and the choices that they make. In all the training events that we have been promoting in Portugal our main worry is the impact the training will have on the teacher and how this training will impact their students. How effectively the mechanism is contributing to a shift in the way we educate the students. In our training events we insist in telling participants that our courses are not about the specific tool or resource we are presenting but mainly about the competency they are acquiring which can be transferred to multiple other situations. All these projects helped us understand what is necessary to overcome the multiple barriers faced by teachers when facilitating learning: personal barriers and external ones as well. In a nutshell, the recipe for the success of a training course is how motivated and supported the teachers will feel. All the projects presented in this chapter are bringing innovation to the hands of the students. Cutting edge science suddenly is transformed into a powerful tool to engage and motivate students to build strong science literacy and perhaps to consider following a science related career. But how this model, as presented in this chapter, is being used for more than 25 years by the Hands-on Universe project. Robotic telescopes have been available for decades and data repositories have also been freely available for many years. What is the missing component to ensure all these trends and possibilities will finally invade classrooms at a sufficient scale? One attempt is presented in the next chapter where a favourite student topic is transformed into a science experiment. In "Black Holes in My School" an exercise is presented that helps students reproduce the discovery of a stellar mass black hole candidate. A detailed procedure is designed, and some evaluation tools put in place.

5. When innovation reaches the classroom – Black Holes in My School

Figure 56 A composed image of important moments of the project

The introduction of modern science in classroom is always a challenge, to teachers worldwide, , in particular when dealing with topics that are a target of continuous research. In general school science curricula tend to be more conservative and avoid the inclusion of cutting-edge science, tending to opt for well-established concepts. This on many occasions represents the exclusion of modern and important topics such as high-energy physics and black holes. In our vision there are alternative ways to safely introduce such topics in the framework of the curricula and provide students with the opportunity of inquiring their way in the arena of cutting-edge science. "Black Holes in My school" (BHIMS) is a project that aims to test such assumptions by engaging middle and secondary school students in real research in the field of stellar black holes. The strategy designed for the initial implementation of BHIMS was divided into several actions (Figure 56):

- Preparation of educators by providing them with an introductory course on Black Holes in the form of an OCW (Open Course Ware)
- Support educators by conducting a masterclass, related to black holes, to their students
- Facilitating the use of research facilities to students willing to pursue advanced research

This Project counted on the support of the Faulkes Telescope Educational Team, more specifically from Dr.Fraser Lewis, an expert on low mass X-ray binaries (stellar mass black hole candidates), who reviewed and helped finalize the content of the course and provided online support to teachers and students. The project was developed using several platforms, ICT tools and instruments.

- Moodle for the construction of the course,
- Sonnette for the registration and enrolment of the participants of the course,
- Go-Lab for the creation of the inquiry learning space that embedded BHIMS exercise,
- Images from the Faulkes Telescope, 2m mirror telescopes based in Hawaii and Australia,
- Salsa J – an image processing software for astronomy education,
- Google Spreadsheet,
- Adobe Connect – video conferencing facilities.

This structure led, as a "side effect" consequence, to the improvement of the competence profile of teachers on the use of collaborative tools, ICT infrastructures and remote equipment.

5.1. Developing the Concept

"Black Holes in My School" is a research project that aims to explore the impact of engaging students in real research experiences while learning new skills and topics addressed in the regular school curriculum. The project introduces teachers to innovative tools for science teaching, explore student centred methodologies such as inquiry-based learning and provides a setting where students take the role of an astrophysicist researching the field of compact stellar mass objects in binary systems. Students work with already existing data and use the Faulkes Telescopes, two-meter mirror robotic telescopes, to acquire new data.

5.2. Black Holes in My School Open Course Ware

Figure 57 Key words symbolizing the Open Course Ware

The online course was developed using the framework of the project SonetTe supported by the University of Coimbra (partner of SonetTe). The main aim of SonetTe was to develop online educational open courses (Figure 57), to promote international collaborative research and ultimately to analyse which strategies are necessary in order to promote teacher's professional development. The chosen topic for this joint venture was related to challenges faced by teachers when trying to engage and motivate students for science courses and careers.

Black holes are frequently a topic of interest of students and can be used to promote several different student's competencies while targeting curriculum content. The "Black Holes in My School" course was designed to introduce teachers to basic aspects of black holes and their research, to introduce them to innovative tools for science exploration in schools and ultimately to conduct collaborative work among their students while exposing them to inquiry-based learning enriched by technology.

The **Learning Objectives** went beyond the learning about Black Holes. The main idea was to use the theme to enable participants to:

- Integrate the use of specific tools and resources in their daily lessons (inquiry platforms, robotic telescopes, etc).
- Understand the necessary steps to ensure a good team dynamic in classroom for applying the IBL (Inquiry Based Learning) methodology.

- Understand the complex nature of teachers' professional knowledge and especially the technological pedagogical content knowledge of inquiry science learning methodology.
- Evaluate the impact of the use of such methodology and evaluate the possibility of spreading the example to other topics or fields of expertise.

The main **Tools and Resources** used during the course were: Go-Lab portal and authoring tool, the planetary software Stellarium, the Faulkes Telescopes and Salsa J image processing software.

The course was built on Moodle[28] and the online communication was performed using Colibri (a collaborative service provided by FCCN at the time of this course, based on Adobe Connect). A Facebook group was also created to foster collaboration and communication among the participants.

The course was organized in modules, one per week, and had the following structure (Figure 58):

Week 1: Introduction - Overview of the objectives of the course, modules, tools and resources
Week 2: MODULE 1 - Introduction to Black Holes
Week 3: MODULE 2 - Some ICT tools for education (Stellarium, Salsa J, Robotic Telescopes)
Week 4: MODULE 3 - Observing with Faulkes Telescope and Introduction to Image Processing Software
Week 5: MODULE 4 - Inquiry Learning Spaces
Week 6: MODULE 5 - Photometry Techniques
Week 7 and 8: MODULE 6 - Observing Stellar Black Holes
Week 9 and 10: MODULE 7 - A black hole at the centre of our Galaxy
Week 11 to 13: MODULE 8 - Using and creating inquiry scenarios
Week 14: MODULE 9 - Measuring the impact and satisfaction on educators
Week 15: MODULE 10 - Measuring the impact on student's satisfaction and learning
Week 16: Evaluation and Reporting

[28] http://galileoteachers.academy/enrol/index.php?id=2

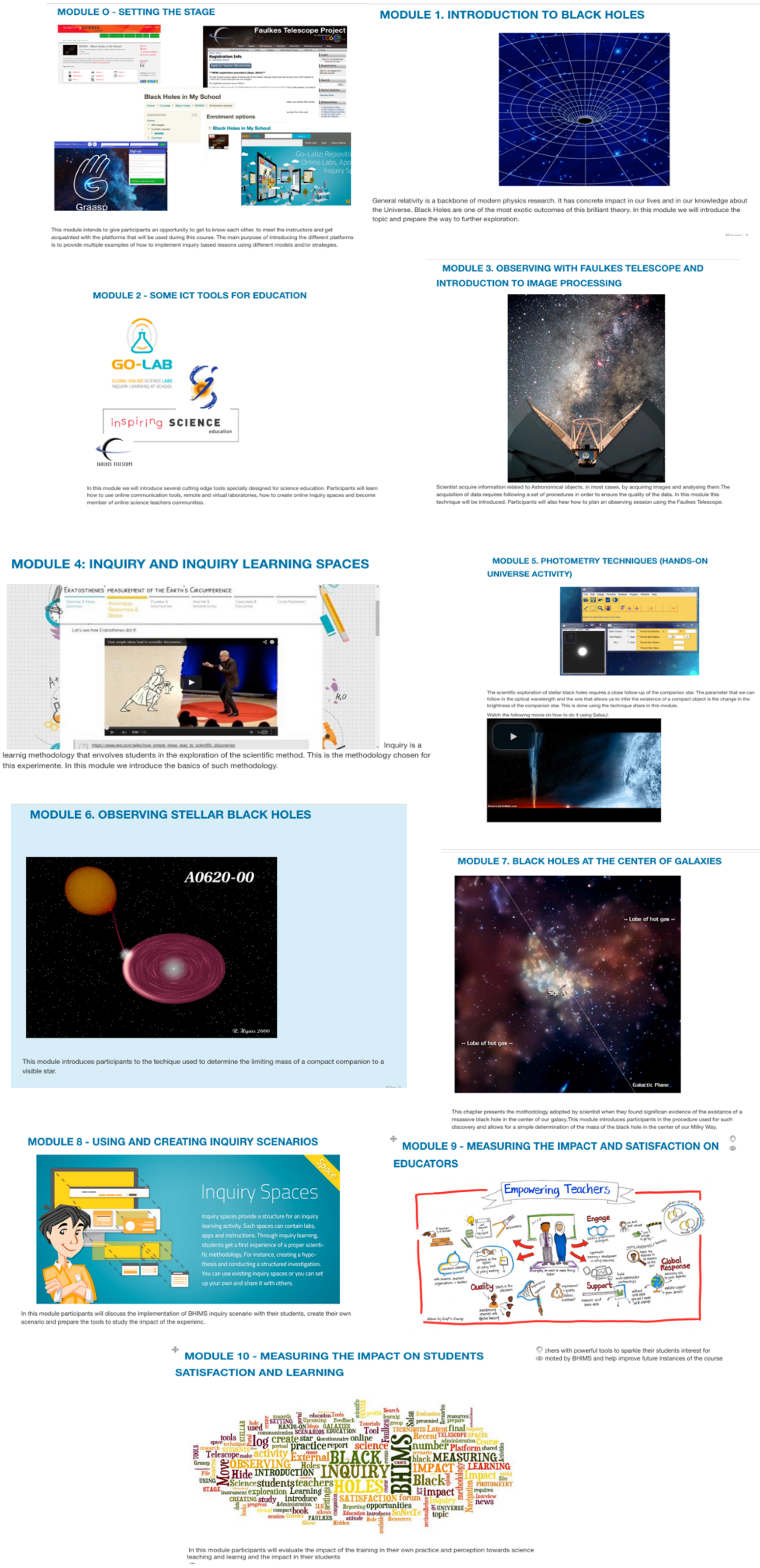


Figure 58 Thumbnails of the BHIMS course

The course was implemented during the months of March to June 2015 and had around 34 registered participants of which 11 followed almost all of the modules. The last 2 modules were implemented during the visits to the schools. In order to keep teachers motivated a series of online sessions (Figure 59) were conducted and all the steps were discussed with all the participants in order to validate and assess its feasibility to be used in classroom. The course counted with the support of experts in the field of stellar mass black hole candidates.

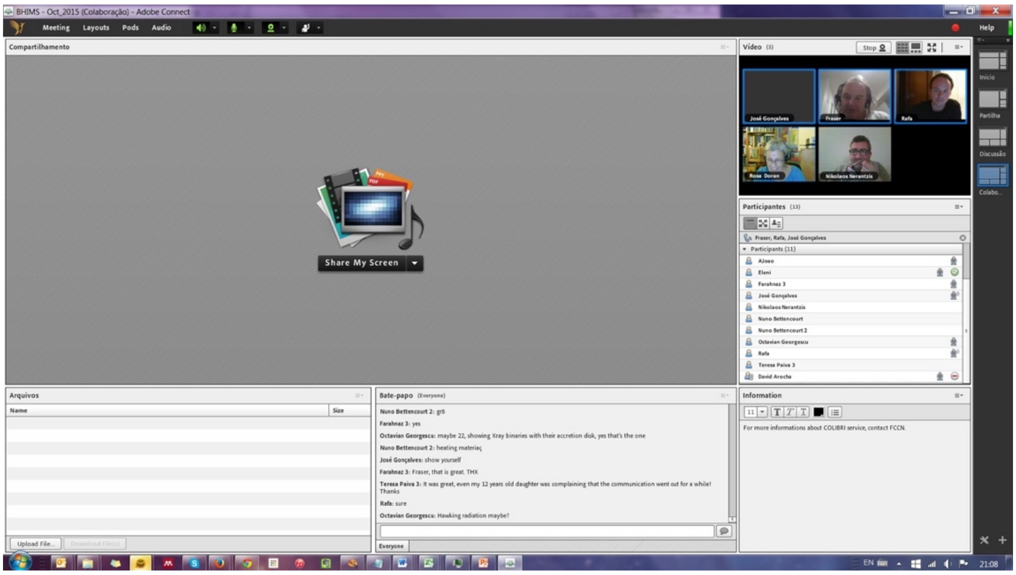


Figure 59 Image of an online session for the OCW BHIMS

The structure for the assessment of the course is presented in Appendix II:

5.3. Implementation in schools

To support the implementation of the course in schools an inquiry learning space was created using the Go-Lab authoring tool[29] (this tool will be presented in Chapter 6). The scenario followed the 5 steps of IBL (inquiry-based learning): Orientation, Conceptualization, Investigation, Conclusion and Discussion. In this particular example the conceptualization was embedded in the investigation phase and an advance research step was introduced.

In the **Orientation** phase the topic of Black Holes is introduced, and a series of short videos presented with the purpose of sparking the interest of the student towards the topic. In the **Investigation** phase, that in this particular case was a mix of conceptualization and introduction to black hole research, a series of documents are presented introducing the user to the basic concepts about black holes and their observation techniques. A full tutorial on image processing using Salsa J is also included. Students find there a quick guide to photometry (measurement of light) and the subsequent creation of a light curve (a graph showing the variation in the light received from a certain object over a period of time). In this phase students are presented with a collection of images of the black hole candidate XTE J1118+480 taken with the Faulkes Telescope[30].

[29] https://www.golabz.eu/ils/black-holes-in-my-school
[30] http://www.faulkes-telescope.com/

This low mass x-ray binary was discovered by the Rossi X-ray Timing Explorer (RXTE) on March 29th, 2000. It is a compact object with a mass that seems to be greater than 6 $M_\odot$ (solar masses). These compact objects are usually discovered when, for some yet not fully understood reason, they emit large amounts of X-ray radiation. In fact, this emission doesn't come from the compact object itself but from the accretion disc that surrounds it. This objects frequently have a companion star whose brightness changes during its orbit and carries with it the signature of what might be a black hole candidate.

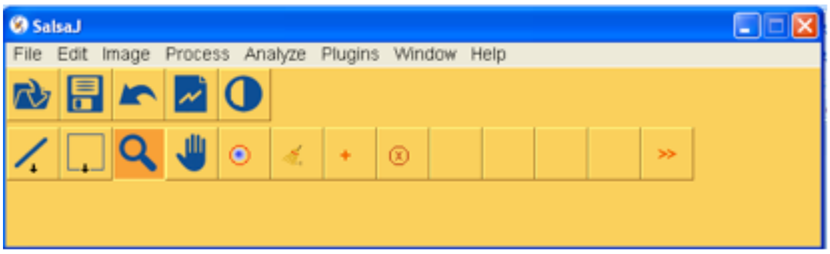


Figure 60 Menu bar of the Salsa J image processing software for students

After installing Salsa J (Figure 60) in their computers and following the instruction sheet students are invited to reproduce the light curve of this objects discovering that it clearly presents evidence of variability that could be associated to a star orbiting a compact object (Figure 61). The full exercise with all the physics behind the discovery of an black hole candidates available for teachers and students can be found in Appendix IX

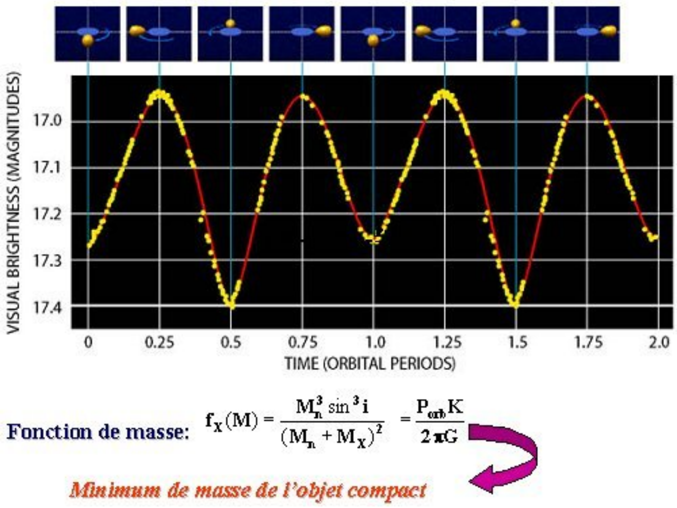


Figure 61 Light curve of a low max x-Ray binary

Next an **Advanced Research** phase is presented where students willing to pursue the research further have the opportunity to work with a scientist in the field of stellar mass black hole candidates' observations and contribute to the research in the field. The next phase is the **Conclusion** where students are invited to present a full report of their research in the format of a paper. Finally, the last phase, the **Discussion** where students are asked to present their findings and discuss it with their colleagues. In this particular case the work is to be done collaboratively among all students of each particular classroom.

5.3.1. For teachers


Figure 62 Figure 4 ESA-GTTP training 2014

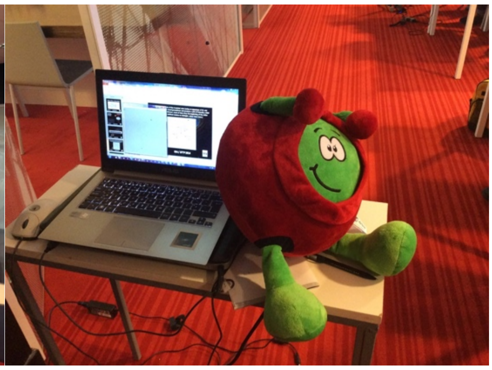


Figure 63 ESA's mascot PAXI observing the course

Besides the online course, a face-to-face course (3 hours) was conducted during the ESA-GTTP (European Space Agency – Galileo Teacher Training Program) course in 2014 and 2015 (Figure 62) and (Figure 63). The course was also implemented with a group of teachers in Madeira and in Spain. The main idea was to present to teachers the material produced to support the implementation in schools. As described above the whole material is prepared and presented in the Black Holes in My School ILS. During this training, teachers participated as students and tutors presented the whole project, as they should do with their students. Teachers liked the experience and provided very valuable feedback during the session. Teachers participating at the ESA-GTTP training are usually experienced teachers coming from 20 different ESA member states.

The result of their participation in this activity as students can be seen below (Figure 64, Figure 65, Figure 66). The ellipsoidal modulation of this graph (red curve) is a clear evidence of the existence of a star orbiting a compact object, usually associated with an accretion disk. The blue line is the average brightness of 3 other non-variable stars and serves as a comparison to support and help "clean" the data. All the necessary explanation can be found in the Moodle course and in the ILS. For the purpose of this study the data has not been further processed. The simple graph with the unprocessed brightness is already enough to present our case. We can immediately see that the star under study has a completely different behaviour to the other stars. To be noted however that the behaviour depicted in the light curve can also be associated to other astronomical phenomena (not included in this exercise).

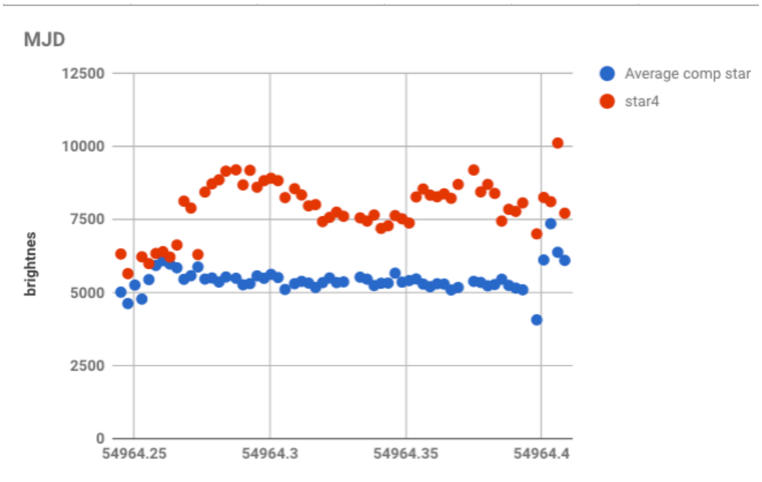


Figure 64 Participants of ESA-GTTP 2014 teacher training session

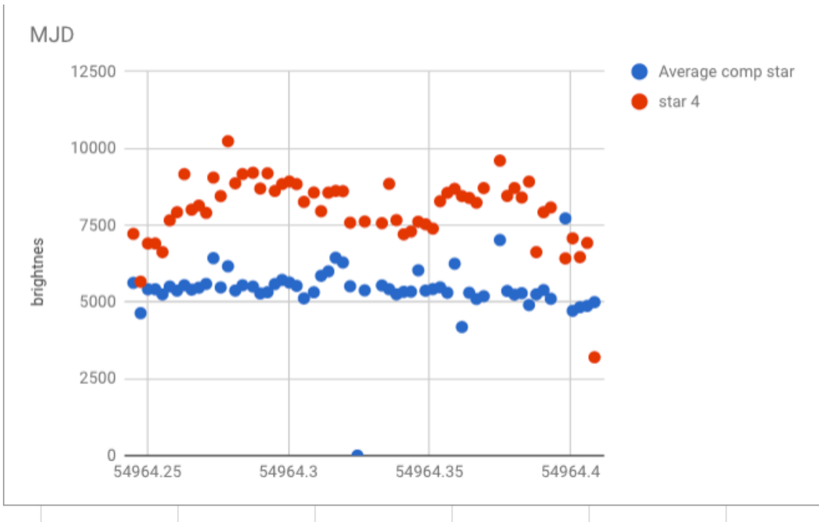


Figure 65 Participants of ESA-GTTP 2015 teacher training session

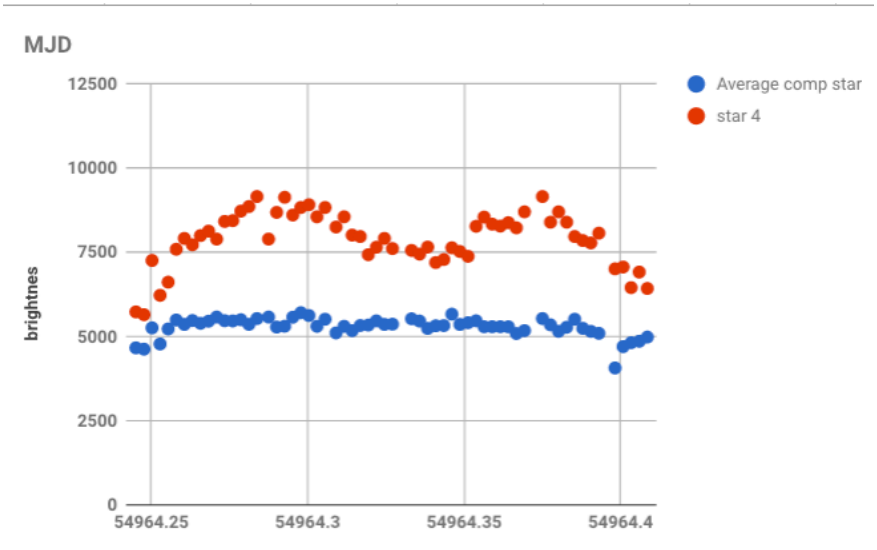


Figure 66 Participants of Teacher Training session in Funchal – Madeira

5.3.2. For Students (Master Classes)

It soon became clear that teachers needed a lot more time to reflect and adopt the BHIMS proposal. So, in order to test the model, a series of sessions in schools were conducted. The sessions were structured to last around 3 hours. In total a series of 10 sessions, involving approximately 300 students, were conducted including the following schools (Figure 67, Figure 68, Figure 69):

- Escola Profissional de Almada – Portugal
- Externato João XXIII – Portugal
- Escola Secundária Maria Lamas – Portugal
- Escola Secundária Fernando Lopes Graça – Portugal
- EB2,3 Conde de Oeiras – Portugal
- Escola Básica de Santana – Portugal
- Colégio Corazon de Maria – Portugal
- Clube de Astronomia da Ilha do Príncipe – São Tomé e Príncipe
- Escola Secundária Matias Aires – Portugal
- Escola Dona Maria II – Vila Nova da Barquinha – Portugal
- Escola Básica Carlos Gargaté
- Escola Manuel de Figueiredo

The sessions started with a presentation about black holes in general and then a brief introduction on how astronomers find stellar mass black holes candidates. After a break, students were introduced to Salsa J and finally guided through the necessary steps when studying images of black hole candidates. Students would then start analysing the collection of images, provided by the Faulkes Telescope team, themselves while learning how to work collaboratively with their colleagues in order to achieve the expected result.

The whole process was greatly simplified (when compared to the online course and tutorial) where the whole photometry explanation (the procedure to measure the brightness of a given star) was presented to students participating in the masterclasses but they didn't have to engage in understanding how we determine the specific parameters to perform the task. They were given a collection of around 60 images of the black hole candidate XTE J1118+480 and each student had to analyse 2 to 3 images. Their mission was to measure the brightness of the companion star of this black hole candidate. They also had to measure the brightness of 3 other stars for the purpose of comparing their average brightness to the black hole candidate. Their measurement was added to a google spreadsheet (used by all the students simultaneously) and a graph was automatically produced presenting the variation of the brightness of the 4 stars.

Because of the short time variability of this specific object (the orbital period is around 4 hours) and the fact that the collection of images was taken during a single night, the ellipsoidal variation could be easily seen. As a result, it was very simple to show the students that the star orbiting the massive object had a different behaviour than the other 3 stars. We ended the session by explaining that the graph that they obtained was a strong indication that the star they have studied was orbiting a massive compact object.

Figure 67 Students of Escola Secundária Lopes Graça

Figure 68 Colégio Corazon de Maria

Figure 69 Students of Escola Secundária Maria Lamas

In the images below (Figure 70 to Figure 76), we can see the results of the several classes that participated in this pilot experience. The difference in the results are due to the quality of the collaborative work performed by the different teams of students, to the care they took while making the measurements and transcribing the results to the spreadsheet. All of this was discussed with each team at the end of each session[31].

[31] Salsa J automatically measures the brightness of the star when running the photometry tool and as a result the value is the same for all students. It also centres the star. The variations in the different graphics presented are mostly there due to students entering the values in the wrong cell in the collaborative spreadsheet.

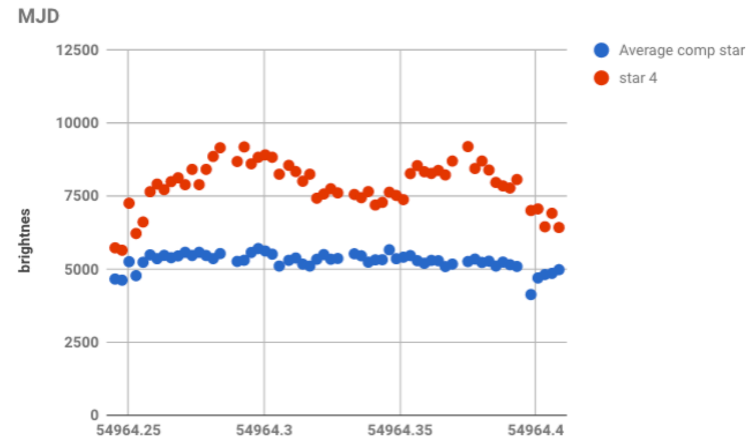


Figure 70 Escola Profissional de Almada - Turma 1

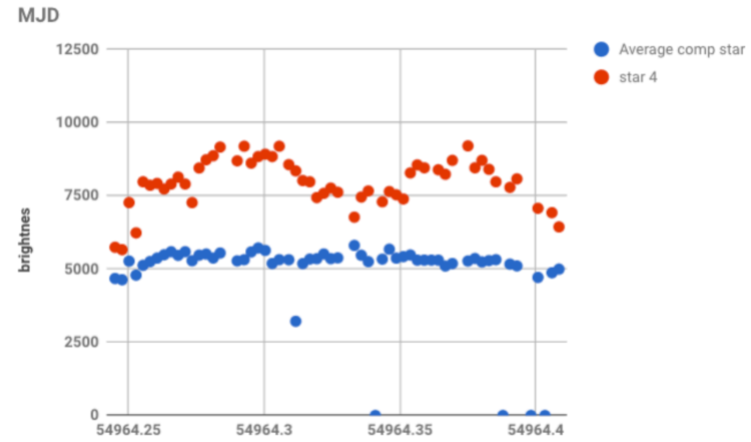


Figure 71 Escola Profissional de Almada - Turma 2

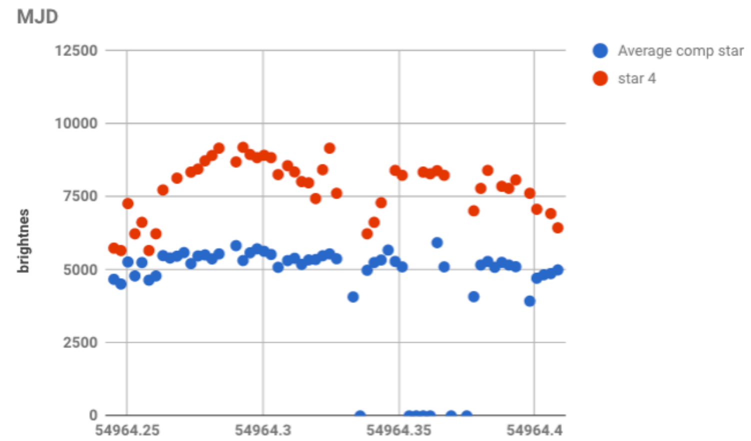


Figure 72 EB 2,3 Conde de Oeiras

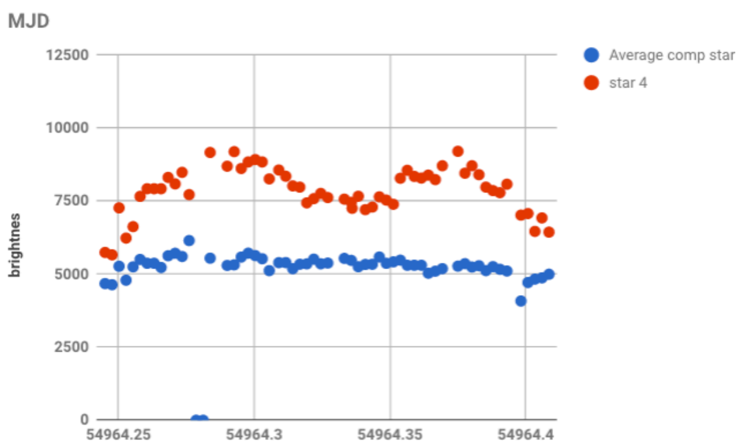


Figure 73 Escola Básica de Santana (Madeira)

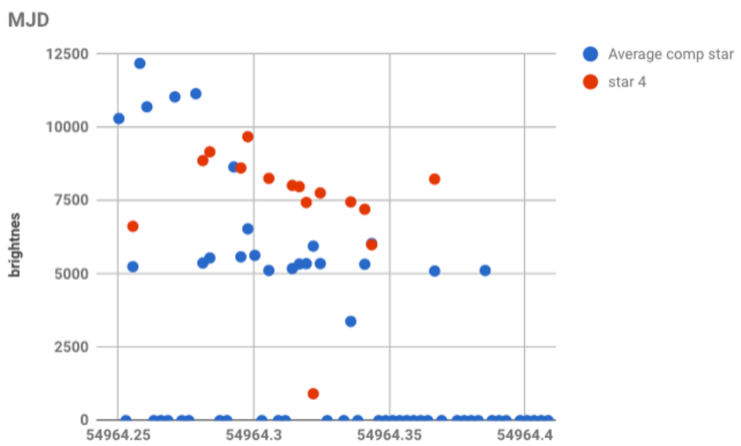


Figure 74 Externato João XXIII

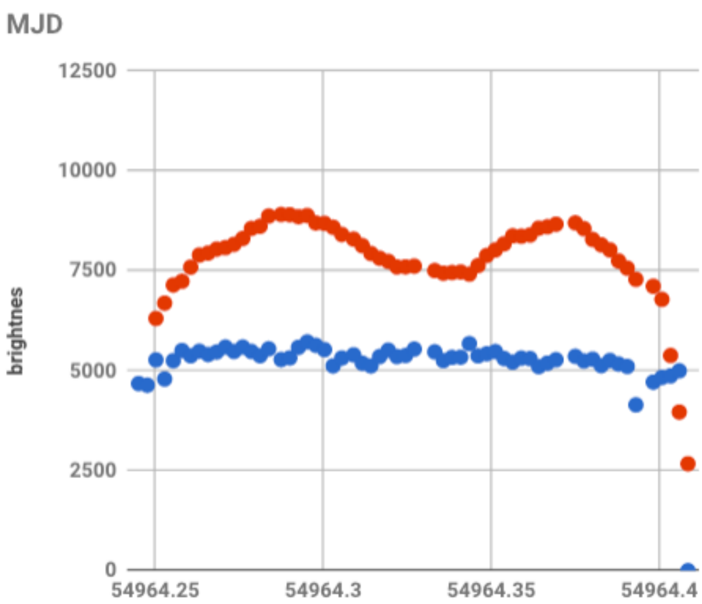


Figure 75 Colegio Corazón de María

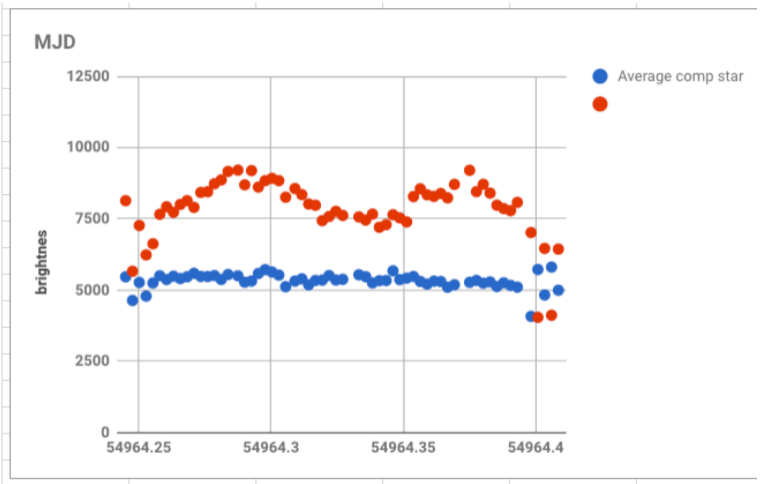


Figure 76 Astronomy Club in Principe Island

5.3.3. Impact

Teachers

In order to evaluate the impact of the project on teachers we asked them to fill out a pre-questionnaire before our visit to their school and/or training session. A second questionnaire was presented after the session. Below are the main results found in this study. In total 88 teachers, from 21 countries, replied to the pre-questionnaire but only 11 replied to the post-questionnaire. With this number is not possible to retrieve proper statistics on the impact but we can infer a few important conclusions:

Teachers that replied to the questionnaire came from the following countries: Belgium, Bulgaria, Colombia, Spain, Finland, France, Germany, Greece, Hungary, Iran, Ireland, Italy, Latvia, Netherlands, Poland, Portugal, Romania, Slovakia, Turkey, United Kingdom, United States of America. Nearly 100 teachers were invited to participate to the survey.

- Over 75% of the teachers that participated in this study have Masters as their higher degree,
- 45% of them have science clubs in their schools,
- 59% of them were teachers from secondary schools (15-18) and 37% from primary and middle school (11-14),
- 62% are teachers of physics / chemistry,
- Their initial knowledge related to black holes was very low,
- 80% of the participants knew what Inquiry Based Learning was but only 65% use the methodology in classroom. This answer contrasted however with their statement when having to choose from 1 (not very capable) to 5 (very capable) showing that their self-confidence is not so high.
    - 1 – 25%
    - 2 – 15%
    - 3 – 25%
    - 4 – 22.7%
    - 5 – 9%

- When asked if they could fit the IBL methodology in the framework of the curricula we see that not everyone considers this an option.
    - 1 – 15.9%
    - 2 – 22.7%
    - 3 – 27%
    - 4 – 15.9%
    - 5 – 14.8%
- When asked about the use of ICT in classroom it became obvious that technology is still being used with the basic tools (the most common are presented below):
    - Power point presentations – 95%
    - Text Editors – 49%
    - Spreadsheet – 49%
    - Simulations and remote labs – 51%
    - Digital tools – 80%
    - Data Repositories – 27%
    - Social Media – 45%
    - Wikispaces – 24%
    - Moodle – 33%

- When asked if they would invest their time to get acquainted with the necessary techniques to study these objects in order to teach their students 95% responded positively,
- When asked if they would like to have more opportunities to involve their students in real research experiences in the field of Astronomy 97% responded positively,
- 95% of the teachers stated that their students like science subjects and 92% felt that their students would choose a career that involves using science,
- When asked about the support of their school principals in a scale of 1 to 5 (1 being the worst value and 5 the best) the following values were chosen, revealing that not all teachers feel supported or at least that the level of support is far from the desirable one.
    - 1 – 20.5%
    - 2 – 10.2%
    - 3 – 36.4%
    - 4 – 17%
    - 5 – 15.9%
- In terms having access to computers or tablets whenever necessary the answers were distributed from 1 (rarely) to 5 (always):
    - 1 – 20.5%
    - 2 – 22.7%
    - 3 – 21.6%
    - 4 – 19.3%
    - 5 – 15.9%
- When asked about the possibility to integrate the research about black holes in the regular class hours 70% responded positively. Another curious result as in fact not many of them actually implemented the experiment with their students.

<u>Teachers that participated in these training events were already a selected sample as they are from the start motivated to the topics presented. Their knowledge related to engaging learning models is high but still not everyone is using it in classroom, for a variety of reasons.</u>

The inclusion of IBL in the lessons is still not the common trend and technology is still used only for very basic activities. However their attitude is positive towards the implementation of research experiences with their students. This statement is rather puzzling as we find (and some evidence is presented in this thesis) that examples of such activities are very rare and require a strong support effort from the part of promoters of such opportunities, in most cases.

Their perception on the support received by their schools principals is not at the desirable level and often we find teachers confiding that their colleagues in general are also not very supportive when it comes to bring innovation to classroom, in particular when it is related to science research in classroom.

The results found in this research can't be assumed to reflect the view of teachers in general. These results originated from before the activity was performed and involved only those educators that are naturally interested in such subjects. These results are just revealing the attitude of those educators willing to integrate research in their classrooms and whose attitude is opening important possibilities to their students. We can also conclude that the support they have to engage in such a model of facilitating learning is not always supported by their school's headmasters who frequently impose a very important impediment for the implementation of the project in classroom.

Students

Students were also subject to pre and post questionnaires. They were asked to fill in a pre-questionnaire before our visit to their school. A second questionnaire was presented after the session. Below are the main results found in this study. In total 227 students filled in the pre-questionnaire and 70 replied to the post-questionnaires. This part of the study was only performed with students in Portugal and one school in Spain. Students were requested to create a code for their identification. This was done in order to preserve the anonymity of each individual. From the 70 respondents we could successfully match 50 that responded to pre and post-questionnaires. The pre and post questionnaire answers graphics can be found in Appendix III

Main Conclusion

The population involved in this study was composed of students from 7th to 9th grade (68%) and 10th to 12th grade (30%). Over 68% of the students had the expectation of learning more about astronomy and black holes. From the 70 responders **73%** stated that their expectations were met or exceeded. When asked if they wanted to learn more about black holes in a scale from 1 to 5, the difference between pre and post questionnaires didn't change dramatically although the choice of number 5 decreased significantly, a somewhat disconcerting result. In contrast to that answer, when asked if they would like to work on black hole research in their free time the results (from 3 to 5) improved from 76% to 86%. When asked if they would like to work in other science research topics their pre and post answers presented an positive increase. However, it needs to be noted that the participants in general were already highly motivated.

In general their view relating to the importance of learning science was also already very high. - When asked if they would like to participate in more experiences such as BHIMS more than **60%** responded positively. In an attempt to understand if the improvement of their view related to the importance of exploring black hole we have asked if they would invest in a mission to explore black holes. Their view about this topic changed very much towards a more positive attitude when comparing pre and post questionnaire. When asked if they would like to have a job related to science, we also can clearly shift from their initial mindset with more respondents choosing a higher classification to this statement. The majority of them had a positive view on the importance of science in our lives but still a visible improvement can be seen from pre to post questionnaire. Their classification to the statement "I like to learn science" also shifted positively in general terms.

This was a short duration activity with several different components that had to be delivered in a constrained time frame. Still, in general, it produced a positive impact on students understanding and motivation towards black holes in particular and science in general.

5.4. Case studies

5.4.1. Principe

Figure 77 Students in Principe Island learning to use Salsa J (picture on the left) and working on the project (pictures on the right)

Principe Island was one of the pilot sites where this project was tested. Thanks to Joana Latas, a math teacher living on the island at the time of the implementation of the experience, a group of students participating in the science club were invited to join the Black Holes In My School experiment (Figure 77& Figure 78). The 11 students were from different parts of the island and different grade levels. Only 1 girl participated in the experience but didn't continue until the end. I have visited the island twice and had the opportunity to work with them on two occasions for a period of 3 hours in each session. The interval between the two visits was of more or less one year. I was very impressed with the retention of information the students presented from one year to the other. In the first session they watched with me the movie "Interstellar", learned how to use the image processing software Salsa J and attended a talk about black holes. In the second visit they had a new talk about the topic and completed their research exercise. The result can be seen in Figure 76. They were all very proud about their result and achievement. During my second stay I promoted a teacher training session and the "young researchers" supported me during the whole training event.

The whole experience was made possible due to the efforts of Joana who acted as a facilitator and managed to perfectly organize the sessions. The library was used for the first training event. A few personal computers from teachers on the island and some from the schools were made available for the students. The experiment didn't require an internet connection. The sessions were conducted during the science club regular meetings and were highly appreciated by the students.

The experience in Principe Island was unique due to the constraints faced by teachers and students on the island. The common notion that developing countries can't have access to cutting edge education due to their lack of proper infrastructure has to be changed to a positive attitude towards finding solutions to ensure children all over the world have access to the same opportunities.

Students filled in a pre-questionnaire but unfortunately, due to some bad decisions of Joana's employers in Principe, the social programme in which she participated was unexpectedly terminated and we had no opportunity to present a post-questionnaire to them. So, no quantitative results can be presented for this case study.

.

Figure 78 Students from Principe Island participating in the BHIMS experiment

5.4.2. Nikos Nerantzis – Thessaloniki – Greece

Nikos is a teacher for children with special needs. He was one of the participants of the online training course. Nikos adapted the BHIMS inquiry scenario from Go-Lab to his student's needs and applied it (http://graasp.eu/ils/56489ef40fffcc3250f7feb7/?lang=en) :

Figure 79 Nikos Nerantzis version of the BHIMS scenario

He presented his work (Figure 79) in the Inspiring Science Conference highlighting the participation of his students in the project. His testimony appears in (Nerantzis, 2016). In his words: "our students would never ever dream to research on the variation of a double star, investigation if there is a black hole!"

5.4.3. Philippe Kobel - a case study from Switzerland

The second case presented happened in Switzerland. After attending the online course and having access to all the material produced for teachers, Philippe Kobel, a secondary school teacher, and in charge of an advanced science research studies in his school, decided to propose the BHIMS experiment to his students. In order to finish their pre-University studies, in Switzerland, students have to produce an essay about a specific research topic. Two of them decided to do theirs on the topic of BHIMS research.

It has to be noted that Philippe's background is in the field of solar physics, so research in the field of astronomy was not new to him. In a discussion with him about the feasibility of the project being adopted by other teachers Philippe highlighted that he was not an expert in black holes and had never before built a light curve. For practical purposes his advantage might be lack of fear of investing in a research of this nature and some proficiency in the use of ICT in general. Other than that, according to his view, his knowledge about the topic and procedure was the same as any other teacher joining the project. Philippe's students research projects can be found in the links below:

- Trous noirs stellaires: de l'approche théorique à l'analyse photométrique (Danaé Mühlemann) - https://drive.google.com/file/d/1gGvKcVc_JlgNsA-sWUiVw5bn-BzNfp9b/view
- Travail de maturité: Les trous noirs (Tom Ledermann & Matias Ferrari) - https://drive.google.com/file/d/1QvDQolhldf-gtjW2oKBeJmPpvt0B8MpC/view

Danaé followed a curriculum with strong mathematics and physics component, whereas Tom & Matias followed the standard curriculum (with regrettably little math and physics). Therefore, they do not really have comparable skills.

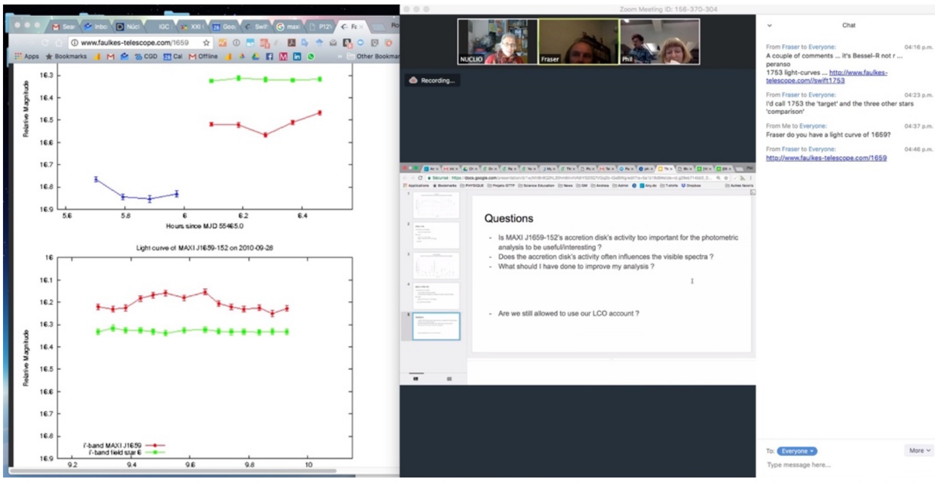


Figure 80 Online session conducted in support of student's research (participants: Philippe Kobel, the 3 students, Rosa Doran and Fraser Lewis)

Danaé Mühlemann Pérez continued her work and conducted an advanced research on a different stellar mass black hole candidate. Both of them received support during online sessions where scientists provided all the necessary support (Figure 80). Her first step was to contact the Faulkes Telescope Educational team and consult them about ongoing observing projects of such candidates. They were not observing any at that specific moment. Danaé decided that she was not going to wait and started looking for new objects and found SWIFT J1753.5–0127. This object was first detected by the SWIFT satellite in June 2005 (Burrows et al., 2005) and is currently being actively studied by experts. She then requested telescope time from the FT team and started building her own light curve of this object. She managed to perform 3 observations and her data contributed to the professional research being done by a team of astrophysicists from Abu Dhabi. As a result of this effort she is now co-author of a paper that is currently under referee to be published in the Astrophysical Journal[32]. Among the authors are some of the most renowned experts in the field, including Fraser Lewis (Zhang, et al, submitted) . My name and Philip's are also in the list of authors. Danaé got an award for her work from the Société Vaudoise des Sciences Naturelles[33].

5.4.4. Participants personal view of their participation in BHIMS

In order to better understand the brilliant outcome of this project a few questions were presented to Phillipe, his students and to Fraser Lewis, the stellar mass black hole expert, supporting the project. The questionnaire was presented to them one year after the project was over. Only one of the students answered the questionnaire. Their answers are presented below.

Philippe Kobel (The teacher)

1) Why did you decide to engage in BHIMS?

As a high school teacher, we can propose each year topics for one-year long baccalaureate projects. Ideally, these projects have to introduce students to research, at least methodologically. After Rosa Doran presented me the idea to use actual optical data of black hole binary systems to investigate black holes mass, I immediately reckoned that this was a brilliant project proposal for the following reasons:

* Black holes are highly inspiring for students (and as a matter of fact, the 3 students who enrolled in the project were highly motivated by the mysteries of black holes)
* The project proposes to implement actual research methodology, which can nevertheless be implemented at high school level: real data, photometry analysis, observing requests on robotic telescopes.
* The project proposed to start by giving students data of the known system XTEJ1118, so students could gain confidence by reproducing literature results (period of system, mass of candidate), before getting into the unknown of taking their own data for a new system.
* The equations to use to find out the mass of the candidate imply high-school level physics: universal law of gravitation, centripetal motion, centre of mass. So, the theoretical analysis of the data is also an excellent exercise for students.
* Rosa Doran had prepared plenty of materials on photometry analysis and on binaries.

2) Do you consider that this experience was good for your professional development?

Sure! Actually, in my gravitation course of the following year, I proposed to the entire class (science focused students) to analyse the data of XTEJ1118 as a lab exercise. And I would love presenting that in the next high school physics teachers congress in Switzerland, as the topic is Astrophysics!

[32] https://ui.adsabs.harvard.edu/abs/2019ApJ...876....5Z/abstract
[33] https://wp.unil.ch/svsn/soutien-a-la-releve/prix-svsn/

3) What were your expectations and were they met?

Yes, for the following reasons:

*all three students could reproduce the light curve of XTEJ1118 and get images from robotic telescopes.

* they were all pretty excited by the topic!

* Students were having the feeling to carry out "real research"!

* Students had the great chance to participate to several videoconferences with Rosa Doran and Fraser Lewis to discuss their analyses. This is an edifying experience for them as such discussions are part of the research life! In addition, they had to do it in English, not their mother tongue...

I am very grateful to Rosa and Fraser for all their time and energy!

Now I would really recommend the project for science-focused students (in Switzerland, who choose the option Math-Physics), as they are more comfortable with theoretical analysis, are familiar with parts of the concepts and can go further without frustration. This is the case of Danaé Perez, who was the only science-focused student enrolled on this project with me. She really enjoyed performing actual research with its frustrating sides as well (despite all weather and priority issues on robotic telescopes). Her thesis has been a success, refereed by the ex-director of the Astrophysics lab of EPFL, and rewarded by a regional prize of the Société Vaudoise des Sciences Naturelles.

4) Please summarize your experience and leave any other comment you might find relevant

For me as tutor it has been a VERY gratifying learning experience as well! Even though I was a user of SalsaJ and did a PhD in solar astrophysics, the topic was fairly new to me, so I had to do my homework as well ;O) Actually, it takes some time to plan ahead what students should do and test it to avoid they hit a wall.

As a minus, I would only say that recording long enough time series of black holes binaries with robotic telescopes has been very difficult since it requires long observing requests and Educational requests on 2m Faulkes are given less priority than professional ones. So, students had to repeat their requests over and over...Danaé got lucky to finally get data just in time, but not the others and this can pose problems in a school project bounded by deadlines.

Note of the author: Danae was the only student who entered the advanced research possibility of the project were students are actually required to observe new candidates in the same way and in fact contributing to research in the field.

Danaé Pérez (the student)

1) Why did you decide to engage in BHIMS?

I had to choose a subject for my « Travail de Maturité » and one of them was linked to BHIMS. I was (and am still) passionate by astrophysics and wanted to learn more about black holes, which I thought (and still think) were fascinating. It was, for me, a great opportunity to approach more professionally and with excellent tools a subject that I already liked.

2) Do you consider that this experience was good for your professional development?

Definitely yes. I learned a lot theoretically and practically, plus I was able, through this program, to understand better how I work and was scientific research is. The responsible of the program were very helpful and helped me a lot understanding how everything worked. But I also often had to understand by myself what was happening, even though I had been given the key to do it alone. Being able to use such professional tools (2m telescopes, great quality images…) was also a big step into the scientific field.

3) What were your expectations and were they met?

I expected to learn about black holes but at first that was my only goal. Then I understood all the possibilities that we had with this program and my main goal became to study a candidate from images that I had taken myself with the telescope that we were able to use. So, I did. My formal expectations were of course met, and I went way further than that in the process. I guess that's one of the very great things with this program: everyone involved pushes you to go as far as you can.

4) Please summarize your experience and leave any other comment you might find relevant

I first learn the theory about black holes. Then analysed XTE J1118 whit images that were sent to us by the responsible of the program. Then we decided to study « our own » candidate. So, we took test-images and tried a few candidates. I finally studied MAXI 1659-152.

Every step in this process was carefully followed by my professor or the responsible of the program but I was always very free and had to learn and try by myself. I think it was the perfect amount of help/loneliness for me to learn a maximum.

Of course, having access to such quality tools was also an incredible opportunity. To summarize, it was an amazing experience for me. As much as a future scientist then as a person who wanted to see how far she could go.

Fraser Lewis

1) Why did you decide to engage in BHIMS?

Like Rosa, I see the science behind exotic objects such as black holes capturing the imagination of scientists, the public and school pupils alike. With the knowledge, experience and telescope facilities I have at my disposal, I wanted to help develop materials which explain something about these objects and shed light on how scientists discover them and improve the theories we have about their existence and behaviour.

2) Do you consider that this experience was good for your professional development?

Absolutely - when work and interest meet, it can be very productive as well as extremely enjoyable.

3) What were your expectations and were they met?

Projects such as this often arise without either expectation or even a natural conclusion. Seeing how they unfold is part of the pleasure of being involved in creating them.

4) Please summarize your experience and leave any other comment you might find relevant

Always an enjoyable challenge working with Rosa and her NUCLIO team.

Note of the author: Fraser presented the project in several international conferences collecting a lot of manifestations of interest as well as curiosity on the outcome of the project (Lewis, 2018)

5.5. **Conclusion**

The hypothesis behind this project was that by providing enough information and support to teachers about the topic of black holes and its research a number of educators would feel encouraged to implement the project in classroom.

Despite the fact that many educators participated in the course and in the online sessions only a hand-full of them, more specifically 9 decided to explore further the concept. From those only Philippe autonomously continued the implementation. The remaining 8 implemented the project with their students with our on-site support.

The general feeling after discussions with all of them was that further training would be necessary but most important than this, Philippe was the only one that had the opportunity to run a year-long program with his students. At the time of the implementation of this experience there was not such an opportunity in Portugal and Spain. The impact on the students that participated in the project is visible and their motivation to be exposed to further instances of such kind of experiments very high. As will be presented in Chapter 6 there are several steps that are necessary to ensure innovative projects take place in the classroom. It requires training and continuous support among other important measures. As a consequence of this study a complete competence profile of innovative teachers and the importance of a strong community building strategy were validated and put in practice as presented later in this document.

6. Go-Lab – Global Online Science Labs for Inquiry Learning at School – from teacher training towards community building and teacher's competence profile implementation

In previous chapters several important results have been presented but an important component was missing. A good evaluation of the impact of the different strategies on the teachers' behaviour, together with what was necessary to ensure the proposed programs and/or strategies successfully reached students. A proper evaluation strategy, during the whole duration of the project, is very important if we want to ensure the success of educational programmes(ICS, 2011). It is important to evaluate the impact on students and teachers. In this chapter we present the strategy designed for the project Go-Lab and the various iterations to understand what were the necessary steps to ensure the project would reach the final users, the students. The scope of this research project didn't allow for the evaluation of the impact on students but gave us a lot of insight on what was necessary to properly empower educators for the implementation of the project to its full extent.

Here we present a very important shift in the perception of what is important to fully achieve the teaching and learning goals of innovative actions. We maintain the same moto: "It's the Teachers" (Burris, 2012), but in a much more broader reach. It is the teachers and all the community surrounding them. It is the teachers and all the professional development they need, to be more than explorers, to become knowledge creators. In this chapter we present the 5 pillars for community building and the competence profile of a Go-Lab teacher. In a nutshell we present the steps towards innovation in classroom.

Go-Lab (Global Online Science Labs for Inquiry Learning at School), was a project co-funded by the European Commission (7th Framework Programme, Grant agreement No 317601). Currently, the platform is being further developed in the scope of the innovation project Next-Lab (Next Generation Stakeholders and Next Level Ecosystem for Collaborative Science Education with Online Labs; co-funded by the European Commission, Horizon2020, Grant agreement No 731685) and GO-GA (Go-Lab goes Africa; co-funded by the European Commission, Horizon2020, Grant agreement No 781012).

The Go-Lab sharing platform is a repository of online labs, supporting apps and inquiry learning spaces created by teachers for teachers.

The Go-Lab Project[34] is a platform that enables rich aggregation of online materials and applications for the creation of science resources for education purposes. It is an innovative approach for science learning in formal and informal environments. It allows the creation of an online inquiry-based learning space (ILS) that integrates online labs, virtual and remote, and the possibility of including useful apps for enriching lessons, links and documents that might be of interest to the topic being addressed. It aggregates over 500 laboratories in 9 different subject domains (astronomy, biology, chemistry, engineering, environmental education, geography and earth sciences, mathematics, physics and technology). Teachers can create unique scenarios for their students not only for the topic being presented in their particular subject domain but also by allowing the seemingless integration of content of several domains

[34] Go-Lab Project: http://www.go-lab-project.eu

in a vertical and horizontal articulation. The platform is continuously looking for new laboratories and in fact, anyone knowing an existing lab that is not part of the repository or an author of labs, may propose a lab to the portal.

The Go-Lab project has as its goals encouraging students to engage in science topics, to acquire scientific inquiry skills, and to experience the culture of doing science under motivating circumstances by undertaking active and guided experimentation, carried out with basic and top-level scientific facilities (de Jong et al., 2014).

In the Go-Lab repository teachers can find virtual labs (simulations) and remote labs (physical labs to which the students can connect and perform their experiments). Some of the remote labs are being offered by important research infrastructures such as CERN and ESA. Students have access also to large repositories of scientific data such as satellite images of our planet, images taken with robotic telescopes, archives of solar images, etc.

The possibility of integrating such laboratories in lessons opens a whole new world of possibility. It enables the opportunity of enriching the laboratory experience of students by facilitating labs for which assembly in a physical lab is not possible. Furthermore, it also allows practice in how to prepare experiments and understanding what works and what doesn't. With the distribution of smart devices all over the world it is now much simpler to offer this possibility to students all over the world. Having laboratory experience is no longer a privilege of few (Waldrop, 2013).

The Go-Lab ecosystem offers possibilities to teachers to create their own scenarios in multiple ways:

1) They can start by choosing a laboratory from the portal that suits their teaching needs. Each laboratory comes with a brief explanation and with the possibility of a preview at their original location (Figure 81). The laboratories are not owned by the project, they are a collection harvested from several different labs and simulation providers including PhET, Amrita, Concorde, among others. After choosing the lab they can request the automatic creation of an ILS that includes the lab. The ILS will be basically empty with only the laboratory integrated in the investigation tab.

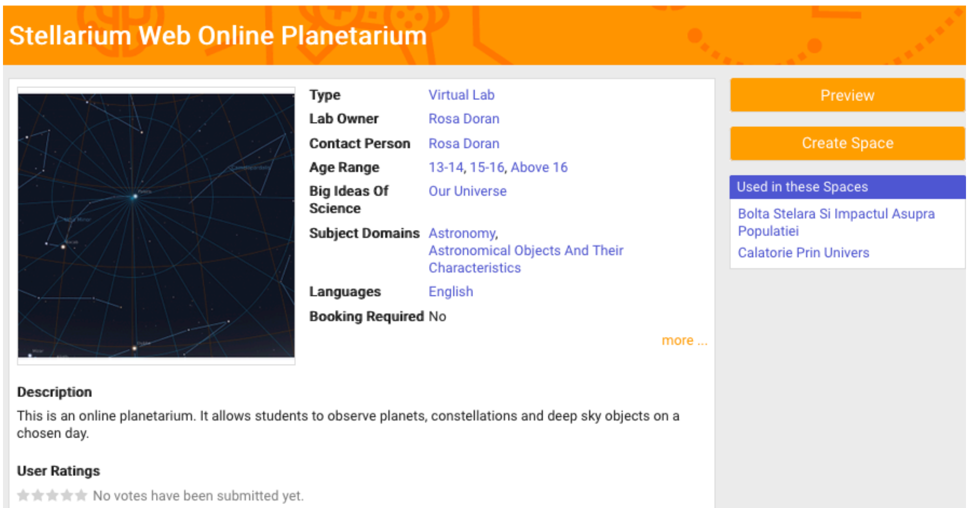


Figure 81 Example of an online laboratory

2) The second option is to copy an existing ILS, available at the Go-Lab portal, produced by another educator. Currently (Dec. 2018) over 900 published ILSs are available. The ILSs can be found in their specific repository or listed under each laboratory, whenever a user has integrated the specific lab in their ILS. Again, the user can preview the ILS and if they like it they can create their own copy of it. They can immediately use it with their students or change according to their needs before implementing it. This time, since the ILS is a copy of the original, it comes with all phases pre-filled (Figure 82).

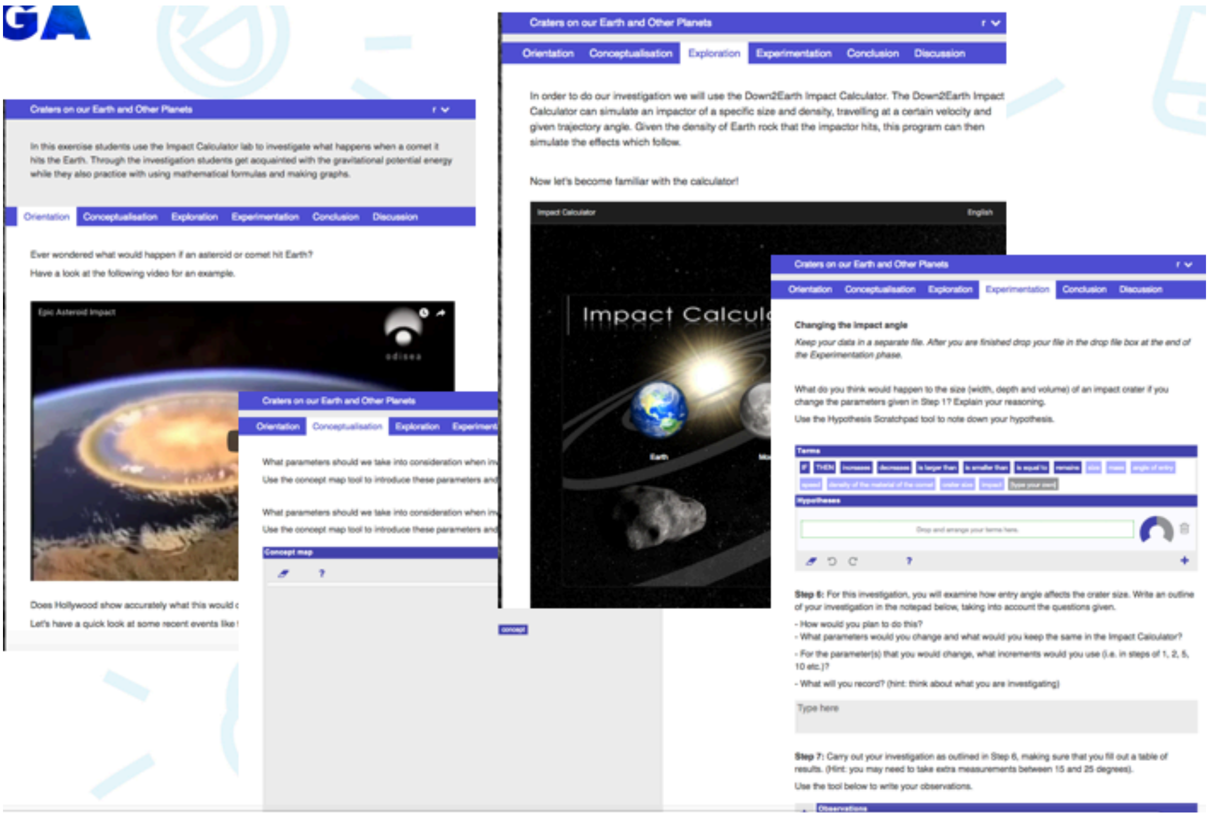


Figure 82 Example of a copy of an existing ILS presenting the different phases of inquiry

3) The third option is to start from scratch directly in the authoring tool. This will produce an empty set of spaces, following the basic inquiry scenario or any other scenario chosen by the user.

The ILSs can accommodate the integration of links, videos, images, documents, etc. It can also be enriched with the use of learning supporting apps. There are 40 apps available at the Go-Lab portal (input box, calculator, drop file, observation tool, hypothesis scratchpad, etc).

There are several types of scenarios that can be chosen: basic scenario, six thinking hats, find the mistake, structured controversy, learning by modelling, learning by critiquing, jigsaw, etc. A full description of each scenario can be found at the support page of the Go-Lab Portal[35]

The platform is presented in various languages and the ILSs can be created in any language.

[35] https://www.golabz.eu/scenarios

There is a series of online courses and support materials in order to help teachers improve their knowledge in the use of the platform and also their own skills in Inquiry Based Learning Methodology (IBL).

Educators can freely choose the type of inquiry they want to use with the students according to their proficiency in facilitating IBL or their students acquaintance with the methodology, and their associated level of learning independency.

This vision is completely in line with the current strategy of the Portuguese Ministry of Education's for the profile of students when finishing school (Martins et al., 2017).

The impact on teachers and students was carefully analysed by a team of experts in the project and the major outcome can be summarize as follows (Tasiopoulou, Ton de Jong, & Martin, 2016):

- Many teachers state that the inquiry learning approach and the use of ICT in their classroom is new for them (this is also applicable to the students),
- Teachers are not used to constructing knowledge based on exploration and experimentation and therefore they find it difficult to start with an ILS that covers the whole inquiry cycle,
- With inquiry learning there is not just one 'correct' answer and there are many routes a student can take towards an answer. For many students, this is a confusing process. Besides getting used to the inquiry approach, students also have to learn how to use the labs and apps that are implemented in ILS's to support them,
- Working with Inquiry Learning Spaces gives students great control over their own learning processes, but at the same time, it demands a lot of their self-regulations skills,
- Students (especially the younger ones) need more instructions (guidance) than teachers envision. Things that might seem obvious for a (more) experienced user (pressing a button or tab, clicking on an item to change its appearance or characteristics) are often not clear to new users,
- Students have difficulties in formulating research questions and hypotheses, in designing experiments and in interpreting the data they have collected. Also, students sometimes have misconceptions or gaps in their prior knowledge which have a great impact on the learning process.

In the same document the authors present a very important list of recommendations:

- Introduce inquiry using the basic features and increase gradually its complexity,
- Make students comfortable with the idea that there might be several solutions to the same problem,
- Provide as much instruction as necessary to facilitate the process and always according to the needs of the students,
- Encourage collaborative work by students when appropriate, balancing the individual and group work.

Also, a series of tips on how to build a good ILS are presented:

- Ensure that the lab is properly contextualized,
- Ensure the prior knowledge is properly retrieved,
- The ILS should be stimulating and interactive,

- Organize text, tools and videos in meaningful units,
- Emphasize the experimental phase,
- Support students in setting up their experiments,
- Encourage students' reflections

Some recommendations for trainers are also provided:

- Prepare teachers and students in advance,
- Encourage collaborative work by teachers,
- Provide time for the teachers to create their own ILS,

The project is now (November 2018) in its second phase and the maturity of the proposed solutions allows in depth understanding of what is necessary for teachers to uptake such innovative approaches and the impact this model has on students. The consortium of the project is composed by experts in the field of pedagogy, ICT infrastructure, teacher training, among other important expertise. It counts with representatives in 9 countries, the National Expertise Centres and also 19 ambassadors in other European countries outside of the formal partnership. At a global level the project successfully reached 147 countries and enrolled over 23.000 registered teachers using the Go-Lab portal (http://golabz.eu) and its associated authoring tool (http://graasp.eu). Still less than 900 of those implemented ILSs with their students. This chapter will describe the methodology adopted by the project in order to maximize the use of Go-Lab infrastructure and evaluate the impact of the different support actions, in other words, what are the evidences coming from those teachers that successfully implemented their ILSs. The main result being presented here is the importance of teacher training and support, in particular the existence of face-to-face training opportunities, in order to ensure the full impact of Go-Lab in classrooms, i.e., to ensure the full implementation of ILSs with students.

A strong network of teachers is one of the tenets for a project's success. But the sustainability and strength of a network relies on several important elements besides the existence of a strong motivation of its members. In the framework of the project Go-Lab we had the opportunity to pilot test and validate the strategy started by Global Hands-on Universe, adapted by the Galileo Teacher Training Program and finally formally structure it in the framework of Go-Lab. I will present below the 5 pillars for community building and the main steps that are considered necessary to ensure maximal uptake and/or support for a specific effort for both projects and an isolated activities.

By empowering educators to apply an effective pedagogical model and using advanced technological structures, Go-lab is supporting the introduction of innovation in classrooms and supporting the construction of solid science literacy in students. This statement is only meaningful if the project succeeds in building a large community of practice that adopts and implements the proposed scenarios in real settings, a community of users that support the piloting, apply the necessary adaptations and engage others in the use of the developed materials (Doran & Sotiriou, 2015).

Having all this in mind, Go-lab aimed to identify current unfulfilled professional development / support needs and requests, define the target users and final beneficiaries (students) and clearly identify the main existing challenges. With this information in hand a strategy was piloted and documented as presented below. In Go-lab this strategy took the form of engagement and training activities, the construction of a support mechanism and a recognition system that will keep the community of users engaged and motivated (Doran & Sotiriou, 2015).

6.1. Characterization of the Portuguese teacher's community during the implementation of Go-Lab

The study presented in this chapter, relates to the Portuguese Go-Lab community and was conducted during the years of (2013-2016). As such it is necessary to understand the scenario under which the actions took place. As presented in (Doran, R., et al, *submitted*), during that period, teachers were facing severe constrains, such as: career stagnation; increase of the number of students per classroom; loss of some non-disciplinary curriculum areas where project based learning could be implemented; and the disappearance of tutorial sessions for students in need of further support. Besides these challenges further constrains were introduced by the Ministry of Education at the time, imposing a greater focus on content rather than competencies. As can be seen in (Coelho, 2016), in spite the fact that teachers know the curriculum very well, they consider it to be very compartmentalized, extensive, and in general not adequate to the age level of students. Traditional teaching, where the educators are at the centre stage was still at the time of this study the most commonly used.

The beginning of the Go-Lab implementation in Portugal coincided with the revocation of the national curriculum for natural sciences based on competences and the introduction of a new curriculum, focused on concrete objectives. This new curriculum brought emphasis on the importance of the process of memorization as a key part of the learning process. It is stated by (Serra & Galvão, 2015)) that never before had the Ministry of Education defined such explicit objectives, leaving little room for teachers' own decisions. The main focus was mostly focused in learning facts rather than acquiring research competencies and other key skills.

Another relevant issue was the challenges related to ICT infrastructure and support at schools. According to the Department of Statistics of the Ministry of Education (DGEEC, 2016), at the time of the study presented in this chapter, there was on average 1 computer for every 3 students and since 2011 all schools have internet access. This number however does not reflect the use of computers in regular classrooms for several reasons: lack of technical support; lack of training for teachers; lack of sufficient internet bandwidth; etc. Among those teachers regularly using ICT, the use was very commonly devoted to less interactive applications such as Power Point presentations, YouTube videos, etc. The statistics presented in the 2018 report (DGEEC, 2018) shows that the numbers didn't improve, in fact in the 2018 report there was an average of 4.3 students per computer.

The scenario for the implementation of Go-Lab in the country was far from ideal but in spite of all the adverse conditions the project thrived in Portugal and helped validate the community building strategies designed for the project. One element that was key for the successful uptake by teachers was the official endorsement of the Ministry of Education of Go-Lab's implementation and that the official launch of a call for schools, done simultaneously in all participating countries, was supported by the European Network of Schools (EUN). EUN is the association of all ministries of education in Europe and promoter of many large-scale projects across Europe. One of the tasks of this partner was the launch of a "call for schools" for all the countries were a national coordinator was in place.

As a final note it is important to mention that the scenario depicted above, as was already mentioned in Chapter 1, changed with the introduction of the national strategy for citizenship education, launched in September 2017 (DGE, 2017) that established new priorities for education in the country. Among other important documents written in order to implement the vision of this strategy the Ministry of Education launched a few important initiatives and documents such as 'the Profile of the Students when leaving compulsory school' (Martins et al., 2017), and the 'Curricular Flexibility and Autonomy' (OECD, 2018a). All these initiatives are listed at Eurydice[36] (EACEA) in the framework of a complete report on education in Portugal. These initiatives are currently introducing very important changes in the whole school approach. However, since the period reported here ranges from 2012 to 2016, the impact of these changes is not accountable for the results presented. Therefore, hereinafter, this study will refer to the status of schools before these changes were implemented.

6.2. The 5 pillars of Community Building and an effective competence profile for teachers – a Go-Lab Legacy

Figure 83 The five pillars of community building

As already mentioned above, Go-lab is greatly contributing to the professional development of teachers, as well as the enrichment student's competence profile. It brings cutting edge tools and resources for science education, a rich collaborative environment, easy integration of modern trends for science education and a strong component of community support coming from national coordinators. The vision of the project is in line with national education guidelines, since 2017, and enables an easy implementation of the vision shared in documents such as 'the profile of students when leaving compulsory school' (Martins et al., 2017).

[36] Eurydice - https://eacea.ec.europa.eu/national-policies/eurydice/content/national-reforms-school-education-53_en

The theory is powerful, but reality always brings unexpected challenges. Between the strong proposal of Go-Lab project, the innovative vision of ministries of education, Portugal amongst them, and the reality of classrooms we have to fine tune a series of variables. There are several impediments:

- One of them and probably the most important one, the lack of professional development of educators in areas of technology enhanced learning,
- The need for an urgent change in the physical settings in classroom towards a more collaborative friendly environment,
- The need to invest in more freedom in relation to ICT integration in classrooms and in a better school infrastructures that accommodate its integration in classrooms.

These are just a few of the shifts that are necessary in order to pave the way for future generations.

This can only be successfully achieved if we have engagement of the school community, if professional development of educators goes hand-in-hand with innovation, if there is a continuous support for innovators and recognition of their achievements. There is a need to support school leaders, pedagogical teams, school's teachers and local communities. This requires a solid community building strategy.

This is the model in which we invested for Go-Lab and present here (Figure 83): The 5 pillars of community building. Part of the vision relies on raising awareness on the importance and effectiveness of existing educational methods. "Marketing" properly new ideas is key to motivate the overall community and promote their active engagement (Doran R. et al, *submitted*). As in any marketing area some "design thinking" is necessary (Lor, 2018)together with a methodology to help understand the needs of a specific target audience. It is important to recognize the existing challenges and opportunities, the main characteristics of the school culture and community. It is necessary to ensure equity and the promotion of a sense of security towards the change to all members up taking the vision and transforming it into their own mission. After finding the change agents in each school/ school cluster, those that are going to pilot the proposed changes and innovation, a new phase beings: - training and support.

A successful professional development enterprise has to be more than just a few hours presenting materials. It has to embody the change it promotes. While inviting them to shift their focus from teacher centred to student centred, and trying to embed a whole community culture and strategy, it is necessary to use the same model being preconized while engaging them in the various training events. The face-to-face events in general have a better impact but a strong online continuous support will make all the difference in terms of promoting confidence in the mission they are about to embark. This support can be materialized in several ways. One form of engagement is to promote from the very beginning the notion of co-creation of solutions, materials, etc. Being involved from the very beginning will empower the target community and naturally boost their confidence in the solutions being reached. Participants will develop a sense of belonging, feel proud of their involvement, and see the project as being partially theirs as well. Whenever possible the efforts of everyone participating in the project should be somehow recognized. It is important to provide certification, promotion of the best practices achieved and giving due credits to everyone's efforts.

After the first piloting phase or even before its end, efforts should be put into building a local community where adopters of the change will find on-site support. This is when the cascade effect will begin, were more experienced teachers will start to train other colleagues and bring the mission to the second stage. The existence of proper communication channels and continuous support is equally important at this stage as it was in the piloting phase.

Table 2 The five pillars of community building

Engagement	Training	Support	Recognition	Community
Visionary Workshops	Face-2-face training	Online Support	Certification & Accreditation	Teacher's Communities
Practice Reflection/ Summative Workshops (face-2-face and online)	Online Training (MOOCs, Webinars, etc..)	Demo Activities in School	Contests	Teacher's Mailing list
Pilot Days (teacher's gathering days)	International /National schools	Teacher's Helpdesk (support page, tutoring page, etc)	Digital Badges	Teacher's Cascade (Teachers Training Teachers)
	Pilot's cascade (teachers training other teachers)		Best Practices (Teachers' and students' highlights, success stories, etc)	International / teacher's gathering events

In Table 2 we present the summary of the framework proposed for the project Go-Lab and tested in Portugal to build the Go-Lab community (Doran & Sotiriou, 2015). This model was the empirical result of the various teacher training events taking place in the framework of the Galileo Teacher Training Program, a legacy of the International Year of Astronomy, endorsed by the International Astronomical Union[37], and the work performed in the framework of European projects devoted to cutting edge research in the hands of teachers and students such as Discover the Cosmos, Inspiring Science Education, just to mention a few. It is composed of 5 pillars with the following key areas: engagement, training, support, recognition and community. In a nutshell these pillars are representing a 5-step approach to a successful engagement of teachers in a project and its subsequent scalability.

[37] Galileo Teacher Training Program – http://galileoteachers.org

6.2.1. Engagement Activities

Figure 84 Participatory Engagement Activities

The first pillar and usually the most important one is devoted to the engagement of the community that we want to reach (Figure 84). During these activities we try to motivate educators with our proposal, we invite them to reflect on its usability and potential interest to address, the needs of their community, to reflect on its benefits and challenges and to propose changes and adaptations. On a later stage participants are invited to reflect on the implementation process, review its impact and localize/validate the methodology adopted.

The initial activities are the so called "**Visionary Workshops**", devoted to present the vision and ideas of what we are trying to bring to their community. It is crucial to present the idea in a clear and appealing way. "First impressions are very important", they have to capture the attention of the audience and make it clear what is the benefit of their involvement, at a personal and community level. It is a space where we invite attendees for an initial reflection of its importance and potential beneficial impact. Usually, from these events, the pilot users will emerge. With their help a strategy is designed, and the first actions planned. The involvement of these members of the community in the co-creation of the first implementation is key to make them feel part of the change they are about to test and implement. The localization efforts should have strong contribution from the benefited populations and as such they should feel part of the starting effort and not just listeners and users. So, we can say that, although with very little tangible and measurable results, the Visionary Workshops are a critical step for the success of the endeavour ahead.

The second round of engagement activities are the "**Practice Reflection Workshops**" (PRW) were we invite participants that were involved in the implementation process to reflect on their practice, the impact it had on their professional development an on their intended audience. These are events where teachers have the opportunity to share with promoters and/or other pilot teachers their experience with the system, their concerns and obstacles faced, their success stories and most important of all, be part of the design of the road ahead. The opportunity is also used to promote an advanced training going more in depth on the process/methodology being adopted. It is very important to have in mind that the future ambassadors of the project/methodology you are promoting are those coming from the group that feels comfortable enough to implement and test what you are proposing and as such are good candidates to ensure the continuation and sustainability of the project. This successfully perpetuates the cycle of engagement of potential users. Thus, having them as active participants in these events is very important.

Finally, we invite implementers to participate in a "**Summative Workshop**" (SW). These are multi-purpose events where we give the floor to the participants to share their success stories and to further reflect on its usability. Participants will make their presentations and receive their recognition trophies. During these events promoters should discuss the steps ahead and how the support will be provided for the next stages of the journey. It is important to remember that usually we are asking the participants to step out of their comfort zone, to put a lot of effort to the adaptation and validation of the project being implemented, to spend a lot of their own time to ensure a successful story. Whenever possible, when planning the next steps, it is important to reinforce that they will not be alone. That support will be somehow provided. These events are a nice opportunity to jointly design a sustainability plan.

When bringing new proposals to schools it is easy to forget that the audience will be the same in the next proposal. So, treating them with honesty and respect, providing them with all possible support, will ensure their trust and willingness to embark in future invitations.

6.2.2. Training Activities

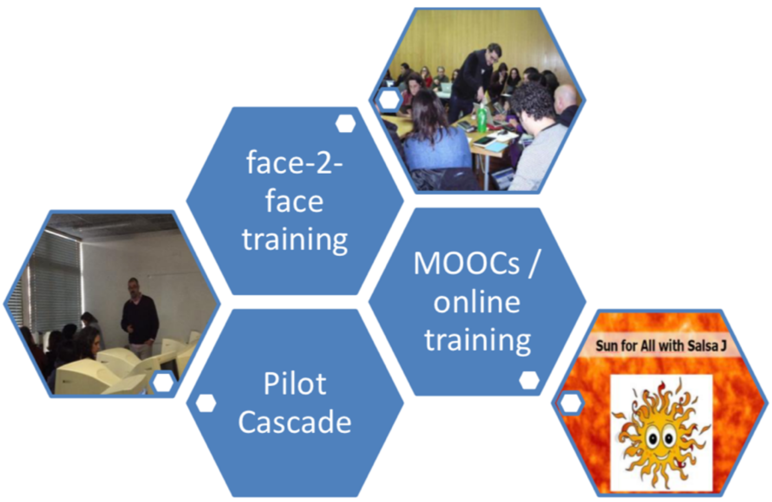


Figure 85 Training Events

The second pillar is related to the training activities (Figure 85) where the relationship between the content provider and the teacher will be cemented. To ensure a solid start, whenever possible, the first training event should be in the form of a **face-to-face event**. Knowing that this is difficult and its scalability challenging, it is by far the most effective way to communicate and share innovation. The eye to eye contact and the possibility to read body language signs coming from the audience helps the conduction of a more user friendly and impactful event. During this event participants are introduced to the whole project approach, tools and resources. The potential benefits expected for their own professional development and for the learning of their students should be presented clearly, as well as the effort and actions that are necessary in order to achieve these goals. During the training, the foreseen obstacles should be discussed as well as potential strategies to overcome them. The training events should be tailored to specific audience needs. Some "design thinking" should be done in order to properly prepare the training. It is important to know the academic level of the participants, if necessary for the project, their ICT competences, the subject they deliver, the grade level of their students, etc. The materials to be used should be prepared accordingly and the delivery method should take all the mentioned considerations into account. If desired and possible, online training resources should be made available. After these events, participants should feel empowered to start introducing their new learning methodologies in their practices, adapt them to their own needs and try different solutions to face the potential obstacles. The better prepared they feel the more likely they will act as ambassadors of the project ensuring its growth and sustainability.

An **online training / MOOC** (massive online open course) can help participants further understand the topics being presented at their own rhythm. They can also be a useful tool, for those willing to, to go more in depth on the different contents. These should be perceived as complementary resources. Spaces were the project content and all presented materials and resources should be found in a friendly format. They can be used as training companions or simply as a reference guide to help them further explore the system.

The sustainability and scalability of the effort can be ensured by a **Pilot's Cascade Strategy.** In other words, to create a scheme were teachers that become proficient on the use of the tools, resources, methodology, etc., can train other teacher or at least share their results and impact. As presented in (OECD, 2014a) the training from teachers to teachers is increasing and becoming an important component of continuous professional development (CPD).

One of the efforts conducted to validate this pillar was the organization of international intensive training opportunities. They took the form of summer and winter schools were teachers from several countries usually pilot teachers, would gathering a culturally rich environment and have the opportunity to meet face-to-face with experts on the project they are involved. During the implementation of Go-Lab three summer schools were organized in Athens. A total of 107 participants from 24 countries participated in these events, of which 15 were Portuguese teachers. As will be presented later in this chapter, the latter scored very high in the number of lessons created after their participation in the summer school and their implementation with their students.

6.2.3. Support Mechanisms

Figure 86 Support Activities

At the heart of any successful project there is a strong support mechanism (Figure 86). This mechanism should provide the necessary aid for pilot implementers and newcomers seeking to start engaging in the project. It has to provide quick and user-friendly answers. To this end, a series of actions that create a support hub and peer-to-peer support platforms should be implemented.

As mentioned above the first step to motivate teachers to pioneer the project in its pilot stage are the so-called Visionary Workshops. From there a fraction of participants should manifest the will to uptake the challenge. The subsequent phase is to provide training opportunities in face-to-face events and online. During the implementation of this framework we observed that even those that already felt proficient in the presented approach didn't exhibit the necessary confidence to engage in the next step, the implementation with their students. Several reasons were presented to explain their reluctance in taking this important step: lack of support from their colleagues, lack of support from the school board and sometimes lack of support and interference of members of the local community (frequently parents). In general, these obstacles were connected to resistance by the various stakeholders to switch to the Go-Lab proposed approach. Inquiry based learning requires more time, ask teachers and students alike to step out of their comfort zone and to many parents it is seen as a deviation from what in their view should be the main goal for their children - performing well in the exams. To that end we designed a peer to peer support strategy, the "Demo Activities". For those teachers piloting the project we offered to visit their school with the purpose of conducting a demo activity. During the demo activity days, we first engaged students in a sample lesson, next we invited the school community to participate in a workshop where the entire Go-Lab approach was presented. After these activities we invited the community at large to participate in a science café where again the overall vision of the project was presented. As a result of these activities pilot teachers felt strongly supported and encouraged to take the next steps.

We also conducted a series of pilot days (pilot teachers' gathering days) with the aim of reinforcing their training, presenting new or more advanced features, ensure the adaptation of specific needs and the active collaboration of all stakeholders in the field. It served as a strong community building effort were teachers from several regions, in Portugal in particular, got together to exchange ideas and good practices. In a recent study the support of peers was referred as a desirable component for professional development as already mentioned in (OCDE, 2014a) and more recently in a study developed by (Higgins et al., 2015).

Go-Lab conducted a series of summer schools. The participants were chosen in general through contests involving the creation and use of ILSs. Two to three participants were chosen from each of the countries participating in the project consortium. These events also acted as support activities since they provided user tailored training opportunities. In summary, the awareness that there is a strong support system in place, that can provide help whenever necessary, further motivated educators to uptake the very often challenging tasks.

Changing education, even in the most advanced and modern countries, is not an easy task. It requires a concentrated effort, not only of the school community but from the surrounding community also. It requires the willingness of the school board, the engagement of teachers, the student's awareness and the local community understanding and agreement of the changes that are to be implemented. The support of educational authorities is also key together with multidisciplinary and interdisciplinary engagement, not only at a subject domain level but in all levels of integration of individuals in such a setting. In the last part of this thesis a discussion of the importance of using a localized and individualized strategy for adaptation, creation and adoption of opportunities will be presented, via a strategy called "Design Thinking for Education".

Figure 87 Support instruments for Go-Lab

Throughout the way the existence of a support mechanism is of the uttermost importance. It builds trust and confidence in the target audience. In Go-Lab the support in the first stages of the project was provided by national coordinators with backing of the pedagogical and technical team. In the current phase a semi-automated system is being used that allows users to present their questions online and within 24 hours a member of the team provides the necessary support. This allows for support to be provided almost instantly to the most common questions and a faster reply to more in-depth support instances. National coordinators also provide in loco support which largely enhances the uptake of the project and its subsequent successful implementation together with a smooth trajectory that consolidates their learning and practice. A series of support material were created and whenever possible translated and localized for each country where national coordinators were available (Figure 87).

6.2.4. Recognition mechanisms

Figure 88 Recognition Mechanism Instruments

The 5 pillars of community building constitute the skeleton of a complex and demanding framework designed to support innovative teachers or educators. Their dedication as facilitators of modern trends for learning require many hours of preparation, re-writing and/or creation of new lessons and research of new ways for delivering content while promoting key competencies acquisition. It also requires constant updating on the use of ICT tools and a lot of flexibility to adapt to the usual infrastructure constrains that exist in most schools. These efforts deserve a proper recognition and as such it has become an integral part of this framework (Figure 88). The recognition can be in the form of certificates, accreditation credits, digital badges, etc. Efforts of educators, students, schools and other important stakeholders should also be duly recognized and highlighted. With this in mind several actions were conducted during the implementation of Go-Lab. For Go-Lab various models were used and adapted to the needs of each country: certificates, national accreditation, badges, etc.

Recognition Activities: For many teachers, certification and accreditation are an integral part of their professional development. With this vision in mind, it is important to investigate how to develop an efficient recognition mechanism that validates the participation of all teachers and eventually recognize their support according to the different levels of commitment. While some actions (such as the digital badges and official accreditation) need more time to be fully developed and applied, other actions such as the international contests may provide immediate recognition; (Doran & Sotiriou, 2015). The relevance of the different mechanisms varies from country to country and often from individual to individual. We propose the use of a variety of options in order to accommodate the expectations of each participant. Equally important is the acknowledgment and recognition of the support provided by the pilot teachers and the recognition of the participation and support of the school in general as well as the involvement of the students. In order to support this vision several instruments were developed for Go-Lab: Go-lab teacher's certificate, Go-Lab Ambassador's certificate, Go-Lab Student's certificate, Go-Lab School certificate and finally and of uttermost importance for the curriculum of educators, the digital badges. In countries were the formal accreditation was relevant for the progression in teacher's careers, there was an extra national certificate. This was for instance the case in Portugal were over 300 teachers were trained in the first phase of the project.

Accreditation: The recognition takes different forms in different countries. In some, like in Portugal, teachers are required to participate in accredited training events in order to progress in their careers. In other countries, like in the UK for instance, such requisite is non-existent. As such, the importance of accreditation, i.e., recognition of an independent institution in general ministries of education, will have different meaning for different nations. Often a simple certificate, a recognition issued by the project coordination will suffice and be very valued by the participants. In Portugal a 25 hours course was accredited by the CCPFC (Concelho Científico-Pedagógico da Formação Contínua), the body empowered to accredit the courses offered by the different training centres. These training courses are hubs that act as an important ingredient for the enrichment of the participants competence profile.

Go-lab certificates were produced and delivered as a recognition mechanism for the various types of engagement. They encompass the recognition of the different stakeholders from the school community, starting with the recognition of the school, going to the teachers and the students.

Digital badges are part of an open badge systems which is now becoming very popular and regularly used as a model of building motivation by users. It is a strategy to reward the acquisition of key skills. The value of the different badges is directly connected to the issuer. To produce the badges for Go-Lab we have used the Credly system. When a digital badge is issued the receiver can display it in their digital curricula, in their social media, etc. This means that by clicking on the badge the user accesses the official page where the origin and name of the owner of the badge is confirmed. This is becoming very popular in Europe and accepted by different organizations as proof of the different competencies in the profile of the owner (Elliott, Clayton, & Iwata, 2014). In Go-Lab 321 badges were assigned to teachers in different categories, following the Go-Lab competence profile presented later in this chapter. Badges were created according to the categories defined in Table 3 and the delivery of such recognition token to students was postponed to the next phase of the project. Five categories were created in total and 321 badges issued

Table 3 Go-Lab badges per category

	Assigned to those teachers that became acquainted with the Go-Lab Portal and have successfully integrated online labs in their lessons. (3 badges issued).
	Assigned to teachers that have adopted and/or adapted an ILSs. (4 badges issued).
	Assigned to teachers that have developed their own ILS. (224 badges were issued).

Assigned to teachers that have successfully implemented ILSs with their students. (81 badges were issued).

Assigned to teachers that have successfully trained other teacher on the use of Go-Lab tools and methodologies. (9 badges were issued).

6.2.5. Community Building Activities

Figure 89 Community Building Communication Channels

The whole process described in the framework so far leads now to the final step, the pillar where continuous support and sustainability can be ensured - the community building activities (Figure 89). The whole description, although presented in a step by step approach, is and should be in fact a round of cycles coming back to the beginning towards the final successful accomplishment of the established goals. The community of users generally start with the pilot teachers and through each implementation cycle is enriched with more stakeholders. This desirable achievement should be foreseen from the very beginning. A properly engaged community will ensure the self-regulation and continuation of the innovation being implemented in the school. Members of the community should be invited to participate at various levels, with their inputs in terms of advice, their actual engagement while implementing the project and through cycles of evaluation and changes that needs to take place throughout the process (Community Places, 2014). To support the emergence of this community and its self-regulation, a series of activities and channels were created. There is no prior definition as to what channels should be used for this purpose, some "design thinking" needs to be done in order to ensure a wise choice of channels to be created. The strategy needs to take into account the size of the target community, its social specificities, location, typology, etc. It is important to consider what types of ICT infrastructures are in place, the level of support provided by authorities, the engagement of the different stakeholders of the community, etc. Other aspects that might be equally relevant are the attitude of your target audience toward innovation and the support they find in their local/school community. For Go-Lab several strategies were adopted. In terms of social media the project opted for:

Facebook – Currently (Feb. 2018) with over 1200 members
Twitter - Currently (Dec. 2018) with over 2300 members

Several pilot teachers and their work have been highlighted on social media.
Pilot gathering days, besides having a key role in the support pillar, also acted as a strong community builder. In particular, the summer and winter schools were a strong starting point for the Go-Lab international community building. The project also tried to propose a forum, where participants could exchange ideas or simply put questions. It proved to be very time consuming to maintain the forum and a constant feeding effort from the project partners was necessary to ensure its use. This attempt was dropped during the second phase of the project.

A strong community has to be self-generated or co-created by involving as many interested parts as possible. It is necessary to ensure that members of the community are properly informed, that their voices have been heard. It should be as inclusive as possible limiting the obstacles and barriers to its growth. Last but not least, and as presented in (Rocard, 2007), being part of a network allows teachers to improve the quality of their teaching and supports their motivation.

6.3. Findings of the framework support questionnaire

In order to further understand the impact of the support activities promoted in the framework of the project Go-Lab, conducted by national coordinators, while following the designed framework described above, we have invited teachers that participated in training events, contests, and summer schools to provide more in-depth information about the importance of the various support mechanism put in place (in total we invited 130 participants of training events and 66 participants of summer schools). We retrieved 71 responses. We summarise here the most important conclusions (the complete analysis of the responses can be found at Appendix IV:

Support

Main Conclusions

Most responders were aware of the different support activities promoted by the consortium with a higher incidence in the summer school, the contest and the online support; **49%** used the provided online materials; **34%** received direct support from a colleague (a Go-Lab ambassador); in general, they considered that the provided support on site and online was adequate and suitable; over **90%** consider the online support page material important.

We also asked responders what other types of support they would have liked to get. They suggested: promotion webinars, the existence of more labs and apps, more support from colleagues and the possibility to collaborate online, more training workshops and finally tutorials on how to use the different labs. But the majority of responders stated that the existent support was enough and adequate.

Peer Support

Main Conclusions

We also wanted to measure to what extent this selected group encouraged other colleagues to take part and use the different supporting tools and mechanisms existent: online support page and training workshops scored high with **67%** and **61%** respectively of responders stating that they have used these activities to engage other colleagues, summer schools and tutoring platform followed with **53%** selecting this option. International contests were selected by **48%** of the responders. Around **82%** of responders stated that they are in regular contact with other Go-Lab teachers outside their schools. And from those over **56%** are in contact with colleagues from other countries. **80%** consider that receiving support from other colleagues or being in direct contact with Go-Lab representatives is important.

In terms of training opportunities these are the findings:

Training Opportunities

Main Conclusions

62 % of the responders participated in the various summer schools; **55%** took part in training workshops (both expected percentages since the sample selected for this study were from summer schools and training workshops); **90%** considered training workshops important or absolutely relevant for their professional development with Go-Lab;
over 50% of responders also considered MOOCs and webinars important; **88%** consider their participation in summer schools important and **78%** considered the online training workshops and tutoring platform important;

In terms of impact we intended to know how the different actions impacted the creation and implementation of their ILSs.

ILS creation

Main Conclusions

46% of respondents from this group have created 2 to 3 ILSs but in total over **20%** have created more than 4. In terms of implementation, **43%** stated that they have implemented between 2 and 3 ILSs in educational settings, **16%** between 4 and 6 and more than **10%** have implemented more than 10 ILSs. These are very encouraging numbers coming from this particular community. As show in the next chapter, teachers that participated in training opportunities are also those that created more ILSs and implemented more often their scenarios with their students. In relation to the creation of their ILSs and their proficiency on the use of the inquiry based learning methodology, respondents considered that the supporting tools and activities were very useful for their understanding of the methodology and thus the design and creation of ILSs. The majority considered that it would be difficult to have created an ILS without the support provided by Go-Lab. However, 20% stated that they could create an ILS without support.

Finally a section devoted to collect information related to the several engagement activities

Engagement Activities

Main Conclusions

35% of respondents recommended the visionary and summative workshops; **40%** the practice reflection workshops; **49%** recommended the participation in the pilot's days; **77%** the participation in training workshops; **46%** recommended to colleagues their participation in the MOOCs and **56%** in the webinars; **90%** of responders recommended the participation in the summer schools; **76%** recommended the participation in online training workshops; **78%** recommended the use of the online support page; **73%** recommended the participation in the international contests; **50%** of the responders considered the several reflection and experience exchange activities important for their participation in Go-Lab; **60%** considered the pilot's gathering days very important for their achievements in the project.

6.4. Identified Strengths & Challenges

6.4.1. Challenge: Lack of peer support

Lack of support from peers is an issue often raised when working with teachers. In fact, in Portugal, there were several reports of teachers encountering silent resistance among their peers which often arises due to fear of changes in the system. In order to address this common complain we tested the creation of pilots communities such as teachers groups in social media where lone users could find other colleagues, in the same countries or abroad, facing similar challenges. Teachers are usually very eager to use such platforms to present initiatives, discuss obstacles and barriers and share success stories. Triggering the creation of local communities of teachers, sharing for instance the same geographical area or teaching the same subject was another strategy adopted in Portugal. Starting with the already presented Visionary Workshops we tried to promote regular gathering opportunities, in several parts of the country, including the islands. In all the places we found of course the so called champion teachers, those that were eager to participate in new projects and opportunities. Those participants that would only come due to the proximity of the event or out of curiosity due to the popularity of the project due to the proper marketing of the event were also present. This was a very nice surprise and as a result the community of Go-Lab users in Portugal achieved more than the expected number for the outcome of the project. In comparison with other successful countries like Spain and Greece, and considering the number of inhabitants we can clearly claim that the results in Portugal were really outstanding. In Jun/2018 these were the indicators:

	Greece	Portugal	Spain
Nº of members registered	465	682	1212
Nº of creators of lessons	288	445	889
Nº of Implementers	43	60	98
Populations	~10.7 million	~10.3 million	~46.6 million

These gatherings were very rich experiences used to jointly analyse the culture of the schools, national directives and strategies to overcome the stiffness of the system in place for education during the time of implementation of the project (2012 – 2016). The system at the time manifested a strong preference on content based learning rather than focusing on competences. As a result, a series of nice examples of IBL experiments in classrooms were implemented while following the strong curriculum demands. Innovation was achieved, with teachers supporting other teachers and providing ideas on how to conduct the desired approach while following the educational policies. It was clear that when there is a will there is always a way and the creativity of the pilots was a very pleasant surprise.

Pilots cascade - To ensure maximal reach of the project, pilots cascade support proved to be a good strategy to adopt. In this model teachers supported and trained other teachers. This is crucial to ensure the desired sustainability. Important to say that this bottom up approach is a slow, but very robust and sustainable effort that slowly supports teachers in their mission to change the educational system and to integrate modern trends for science education in their daily settings. This collaboration among peers tends to extend over time and over projects.

An important component to ensure our presence alongside the pilot's schools community was the creation of a mailing list where direct emails were regularly sent informing them about new opportunities, major achievements and future challenges and expectations. We wanted to ensure that pilot teachers would feel partners of the project, responsible for its successful outcome and success stories to be told. When well designed, this method can be a powerful communication and engagement tool. It is not an alternative to other means of communication such as newsletters or social media posts, etc. The information has to be short, straight to the point and with a periodicity that will not make it loose its relevance for the reader.

In Go-lab we went one step ahead and started a periodical special newsletter where the coordinator of the project, Prof. Ton de Jong, directly contacts the pilot teachers and provides them with first-hand information about the development of the project and praises their expertise and support. It is designed with an informal touch and addressing the individual and not the overall community. The success of this approach can be seen by the % of members of this list (the list of Go-Lab pilot schools) that are regularly reading the emails (over 40%). This is a great success as regularly newsletters in the field of education tend to have a reach of around 21% of the readers.

6.4.2. Challenge: Lack of incentive and recognition

Another severe complaint was that all the effort invested in the project was not recognized or even recommended by many of the participating schools. In Portugal, for instance, attending accredited courses was meaningless for the progression of teacher's careers since they were frozen due to the economic crisis being faced by the country.

The strategy we adopted in Go-Lab was to resort to a strong recognition scheme that could be localized and would fit the requirements of the different competence profiles outlined in the framework of ICT and innovation (as described in 6.2.4).

The recognition of the education authorities was ensured from the very beginning due to the Go-Lab strategy of informing and seeking endorsement of all Ministries of Education where we had national coordinators. The process was in charge of EUN (European Network of Schools, the association of ministries of education in Europe). A call for schools was launched, national coordinators made their selection and the final list was sent to the education authorities of each country for endorsement. This was part of the top down approach, not the preferred one, but useful in terms of the recognition scheme.

6.4.3. Challenge: Lack of training

A simple search on the internet for teacher training on any specific topic will retrieve hundreds if not millions of different possibilities. The problem usually is that most courses presented have a strong theoretical component and little or non-existent practical examples. They are generated to serve many teachers and usually present very little opportunities for personalization and inclusion of all specific needs of the end user. Training opportunities are often associated with projects and/or teacher training institutes isolated actions and very commonly have no sustainability strategy associated with it. The majority have no synchronous support and no human behind the scene to provide the necessary on-site support. This is of course very understandable as this solution would imply a huge investment and 99% of the time this is not part of the equation. One can ask if this should not be changed. Why are there so much funding opportunities to the production of tools and resources and so little support for the promotion of meaningful training opportunities. Something I am eager to investigate as part of my future research.

In Go-Lab we invested heavily in face-to-face teacher training events and ambassadors empowerment so that they could also train other teachers in the already described cascade effect. National and international events such as conferences, summer schools, etc, were conducted in order to provide opportunity to all those willing to learn more about the project and its associated methodology. These events were also excellent instances to foster the creation of bonds between teachers. It was very frequent in these instances to witness the start of collaborations and the design of new joint projects. These collective moments of professional development provided some evidence of a faster change in teacher's behaviour and the improvement of their students learning and behaviour, not something that can be statistically described, but to a tutor this reality was very obvious.

6.4.4. Challenge: Lack of community support

Many educational systems in the world are exam driven, preparing students to perform well in summative events as their main goal. This is the bottleneck of any initiative trying to bring innovation to classrooms, in particular if the main aim is the acquisition of key skills. In most countries, in order to enter Universities, students need to perform well in exams that will enable them to find their chosen future courses. Frequently these exams are heavily content oriented and the preparation for them time consuming and often content memorization based.

A consequence of this reality is that students get very anxious when entering the last phase of the school preparation and want to focus more and more in the preparation to overcome this final challenge before University. Often teachers from high schools would claim that no matter how enthusiastic students become when presented to the new models and experiences, the common reaction is that they don't want to "waste" time in new experiences, they want to be prepared for the exams. Their parents exhibit the same attitude and harsh complains can occur to teachers that try to take a path that is different from the sole preparation for content memorization.

In order to address this issue, in Go-Lab several initiatives involving the whole school and local community were promoted. The main objective was to enable promoters to properly share the importance of the participation of the school in the project, the richness of the existing infrastructures made available to them (such as CERN, ESA, ESO, etc.), the innovative approach of the project and the numerous competencies acquired by the students while exposed to the project and its associated methodology. In Portugal for instance these initiatives took the form of science cafes accompanied by night sky observing sessions.

Visibility of the project is an accompanying measure necessary to emphasize the importance and relevance of the project to the community. As such a dissemination strategy must be put in place. The use of social media was one of the choices for Go-Lab. Social media can be a very powerful tool to build a solid and sustainable community of users. But this only happens if a few important aspects are taken into consideration: posts have to be meaningful for the target audience, relevant to their daily needs or interests and have to be presented in a periodical non-invasive way. Groups in Facebook are very popular among teachers but have to be fed very regularly and work best if we allow for users "ownership" or maybe "partnership" in the management of its content (Doran & Sotiriou, 2015). It can have a role of spreading the word about the project, it is what some marketing people call: "digital word of mouth". In teacher's professional development we don't expect a very large audience but a continuously growing audience of our main target communities. Go-lab project had its own presence in the social media (in English) and several partners used their own social media in their national languages.

6.4.5. Challenge: Relevance to the school curriculum

It is no surprise for those dwelling in the world of education that curriculum constrains are a major impediment for implementation of innovation in schools. This is what we called "curriculum trap". Despite efforts to introduce innovative models for science learning, teachers are often faced with the urge to fulfil the long list of topics they have to cover within one school year.

To support educators in this mission, in the framework of the project, a curriculum analysis was performed in all the participating countries, in order to retrieve the major common challenges across the several science curricula. National coordinators were then able to focus on the creation of ILSs considering the outcomes of this study. In Portugal we decided to re-use a strategy developed in the framework of the project "Discover the Cosmos", the presentation of weekly resources. We called them "Resources of the Week". We used social media to make publicity of such resources and as a result their use by members of the Go-Lab community was increased. They also served as a trigger to bring more teachers to the project.

6.4.6. Challenge: Lack of tools and resources (too many and how to use it)

The use of the "Resource of the Week" also worked as a strong marketing scheme to address another important issue faced by teachers, the existence of too many tools and resources and the very little support there is for their uptake. In places were funding schemes promote the creation of hundreds of even thousands of new resources and where there is no solid sustainability plan, the amount of resources being produced was gigantic. This can be very challenging for educators. It is very common to watch a presentation of a project and find that as an outcome several new tools and resources are now available for free. When watching such episodes of information, one might think that the presenter is a very generous person, but in fact, the person is just another project developer or implementer without any other option rather than hoping that their platform and materials design is good enough to overcome the appeal of competitors. On the other hand, educators feel overwhelmed by the quantity of material and the complete lack of capacity to analyse and choose all that is being regularly presented to them that often the choice is to use none.

In Go-Lab, as mentioned in previous sections, the presentation of the "Resource of the Week" walked hand-in-hand with the information that teachers could have support at any time, from the developer team associated with the reinforcement presented by pilot teachers. This happened when teachers shared their own resources as ready-made examples of material perfectly fitting the curricula for that particular science domain and time of the year.

This strategy helped boost the confidence of educators as they could now see how to implement Go-Lab while covering the mandatory curricula. But it is necessary to say, as mentioned by Andreas Schleicher in his speech[38] during the debate about PISA in Portugal organized by Fundação Francisco Manuel dos Santos. He mentioned that as the world progresses the quantity of information we want to ensure students will receive during their school years is ever growing and at some point we need to make decisions. It is also not a secret that in the era of digital data and ICT infrastructures available everywhere, information is easily accessible all the time, everywhere (well, almost everywhere depending on the level of development of ICT infrastructures country wise). So as mentioned by Schleicher, there needs to be a compromise and maybe we need to understand that now is the time to learn how to learn, to learn how to find good and credible information. As Ian Gilbert mention in his book (Gilbert,

[38] https://www.youtube.com/watch?v=cPYcq2Gi8Cc

2010) the importance of educators now is as facilitators of learning and journey companions. The difference between teachers and students is just their experience and this is precisely what they have to share.

Go-Lab appears in an era were being able to properly handle data and how to be critical thinkers when analysing information are crucial competences for the future world of work if not for the future of humankind. Go-Lab as an aggregator of information is a good example of how ICT can be used to serve the purpose of educators, not the other way around.

To ensure that Go-Lab presented a different approach towards engaging educators, we wanted to listen to users, we wanted them to be part of the creation of something that would be tailored to their needs. Again, this is a marketing strategy called "Design Thinking" and it is as valid strategy for product sales as well as for knowledge sharing. If you don't listen to your target audience you might end up building something that from your point of view is perfect yet no user will ever touch it because you never asked them what they really need/want. With this purpose in mind we created another questionnaire, this time targeting the users of the Go-Lab Portal, the entry point where all the tools and resources developed for the project can be found. The outcome was very important as it helped us better understand what changes needed to be implemented and where support and follow-up was necessary (Doran & Sotiriou, 2015). It was distributed to the participants of the Practice Reflection Workshops and/or to the teachers that had the opportunity to implement Go-Lab in real settings. We wanted to ensure that responders would be teachers that joined us during the reflection phase of the project (as described at the section of engagement activities). In total we had 189 responders coming from all partner countries. Schools in many of the countries of the consortium, at the period being reported in this document, were still not supporting the full implementation and integration of the Go-Lab services. These are the most prominent constrains educators shared with us:

- Time: Too little time to explore new tools and new trends;
- Curricula: Too dense and extensive curricula that doesn't allow experiments;
- Exams: Too much continuous pressure to prepare students for final exams;
- ICT: Lack of ICT infrastructure and support;
- School: Lack of school support.

The Go-Lab Community Building Activities had to take these major restrictions into account and design and develop a sustainable support framework that allow the support teachers need, despite their limited means to learn about, create and implement Inquiry Learning Spaces in their schools as part of the large-scale pilot activities. More specifically, during the implementation phase of Go-Lab, teachers had the opportunity to acquire important key skills through workshops and training to become eventually creators of their own ILSs. Many ILSs are easily adaptable to all types of mobile devices, targeting curriculum content and are designed to fit the classroom time duration. To a certain extent, these examples promote a more in-depth learning on students participating in lessons. In some cases, teachers reported that students required less time in order to learn specific content when presented and addressed with an ILSs. However, it should be noted that the implementation in the majority of the cases was not yet mature enough to ensure a proper evaluation of the (long-term) impact on their performance when exposed to national exams; further studies are required. School support can be expected to increase wherever Go-Lab has been successfully introduced. Success stories and positive teacher and student feedback have been received in the pilot schools. It was clear that any support framework cannot fully rely on only one type of support activity alone but has to simultaneously address various approaches and offer different solutions to reach and help as many teachers in as many countries as possible. In theory, the following all-encompassing framework was designed and developed to answer the existing needs and challenges the education system face and has the potential to offer the best solutions from all the available possibilities.

6.4.7. Findings from the Practice Reflection and Summative Workshops Surveys

The responders for the first phase came from 13 different countries and their distribution can be seen in Table 4

Table 4 Number of responses per country that responded to the online reflection questionnaire - PRW

Country	Number of Valid Answers
Belgium	41
Cyprus	25
Estonia	50
Germany	10
Greece	14
Israel	1
Italy	1
Latvia	1
FYROM	2
Netherlands	44
Portugal	19
Russia	1
Spain	36
Total	**245**

After the second phase of the project we asked the pilot teachers to answer again the online questionnaire. This time 210 participants responded to the survey coming from partner's countries as presented in Table 5.

Table 5 Number of responses per country that responded to the online reflection questionnaire - Final Phase

Country	Number of Valid Answers
Austria	2
Belgium	6
Bulgaria	7
Croatia	3
Cyprus	12
Estonia	15
Germany	7
Greece	40
Hungary	1
Italy	15
Netherlands	11
Poland	6
Portugal	25
Romania	25
Spain	24
Switzerland	1
United Kingdom	4
Other (International Group)	6
Total	**210**

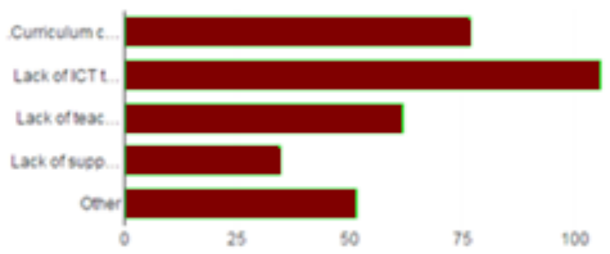
The main outcomes are summarized below, and the complete survey can be seen in Appendix V

Modes of use of the Go-lab Platform and Support

Main Conclusions

More than **40%** of the respondents are creators of new ILSs, nearly **34%** are using an existing one and approximately **25%** are only searching for labs in the repository. Over **70%** of the participants consider that Go-Lab tools as supporting their teaching practice but not everyone think it is possible to introduce them in every lesson. Over **30%** of respondents consider that they had to spend too much time working with the Go-Lab portal but in general they consider it easy to use. The existence of a tutoring platform was not considered important by over **70%** of the participants. The existence of support to the use of online laboratories coming from the school and local communities is dubious and reported as very low when coming from the education authorities.

Main Barriers



Main Conclusions

The choices of the responders of the questionnaires concerning the main barriers encountered for the use of Go-lab in classrooms are, as expected, lack of ICT tools in classrooms and the difficulty to use the existing material in the framework of the curriculum. These were issues that appeared frequently in diverse activities and that were taken into account by the consortium.

Integration in Classroom

Main Conclusions

Teachers are willing to share their ILSs, the resilient ones are the ones that are not confident on the quality of their ILS and reluctant to share for this reason. The ILSs created by Go-lab team are a source of appreciation by teachers.
Users that overcame the resistance barrier to new models and tools **are really considering using ILS systematically in their teaching practice.**

Free Considerations

Main Conclusions

When asked about the more challenging aspects for creating their own ILS the most common comments were related to finding the adequate tools and the lack of stability of the platform. The highlight of the activities pilot teachers implemented was the motivation of the students with the use of labs and apps inbuilt in the ILS. The appealing look of the student view was highly scored when users were asked what they liked the most. The dislike was centred in the labs and ILS with too much text and the prevalence of English language in most ILS, labs, platform etc. The request for support was a common request found in teacher's free comments. Major difficulties encountered during the implementation runs were related to the ICT infrastructure. From the student's point of view the major need was to understand the IBL methodology.

Generally, participants were very positive towards the use of Go-Lab. In Figure 90 we can clearly see that they consider it as a good tool that supports their teaching.

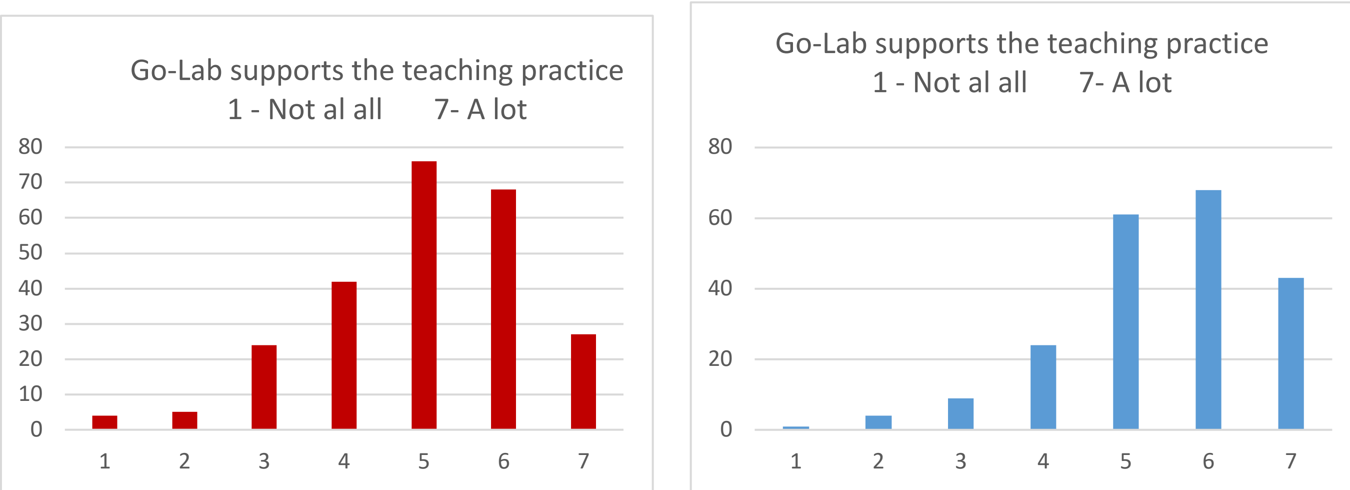


Figure 90 Go-Lab as a supporting tool to teaching – In the left part of the image the result of the PRW survey and to the right the result of the Summative Workshop survey

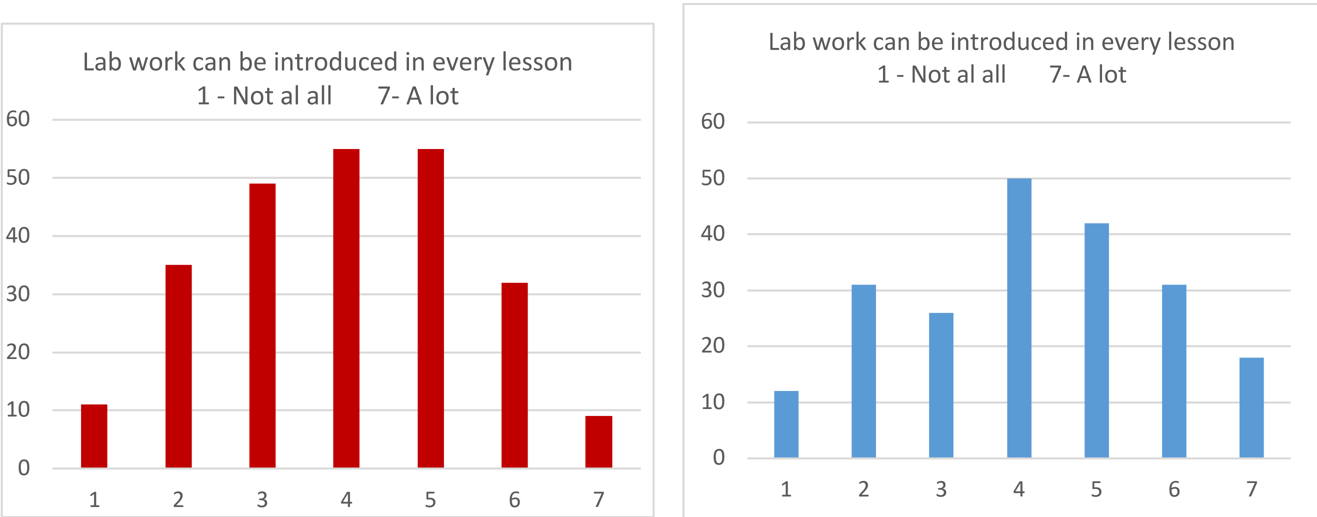


Figure 91 Usage of Go-Lab in classroom - – In the left part of the image the result of the PRW survey and to the right the result of the Summative Workshop survey

Furthermore, a considerable number of teachers introduced Go-Lab in more than one lesson as can be seen in Figure 91. In Figure 92 we see that one of the most frequently reported barriers encountered by the teachers was the insufficient ICT infrastructure; a well know problem that unfortunately could not be addressed at project level. But the lack of ICT literacy as a barrier has decreased, compared with the data of last year's deliverable (Doran & Sotiriou, 2015). However, this has also to do with the sample of teachers that chose to participate in the survey. These are the teachers that participated in the whole process and thus had the opportunity to be part of the training events promoted by the consortium.

The curriculum compatibility of the existing published ILSs continues to be an issue, but this has a tendency towards improvement as more ILSs are now being published. The lack of support coming from the school remains high and sadly this is something Go-lab was unable to address.

Curriculum compatibility – The proposed activities are not part of the curriculum	85	41.7%
Lack of ICT tools in classroom – There are no computers for every student	128	62.7%
Lack of teachers' ICT literacy – Too demanding for me	27	13.2%
Lack of support from school	48	23.5%
Other	27	13.2%

Figure 92 Main barriers related to the Go-Lab implementation as reported by the teachers.

Participants who have not publish their ILSs, (59.3% of responders) reported mainly the following reasons for not doing so: Lack of time and lack of adequate knowledge of the system to ensure quality of the ILS. In some of the reflection events it became clear that teachers fear being evaluated by their work and are not confident enough to make their scenarios publicly available.

Over 95% of the participants of the survey stated that they will continue using Go-Lab in various ways: in addition to their lessons, as support for their teaching, in science research projects, as a complement to experiments with real materials, to continue developing the inquiry skills of the students, as homework.

Go-Lab helped improve the proficiency of 70% of teachers in the use of the Inquiry based learning (IBL) methodology. This was achieved via the training events, the use of already existing ILSs, and the support provided by the project. Besides this IBL competence, 52% of the teachers reported that Go-Lab helped them improve their ICT skills.

In general, the most common issues related to the obstacles met by the users when creating their ILSs were related to finding the appropriate lab and app that would be adequate to be integrated in the curriculum, and at the same time allow them to use the proposed methodology in the provided time available.

For those teachers that implemented or tested the model with students, the most common comment was that students were much more motivated when exposed to the proposed ILS. They enjoyed "playing" with the labs and found the apps very appealing. Some students manifested the wish to create ILSs themselves.

A common issue was the fact that the portal and the authoring tool were different structures. They felt the need to have the labs text translated to their language and commented that several ILSs were not very intuitive.
Teachers in general requested continuous support for the learning and implementation of Go-lab in classroom. Translation and localization scored high in their suggestions and adaptation to their curriculum a very important aspect for their full adoption of the system. Teachers in general appreciated the structure being used to present the tools and resources. They found the methodology very appropriate to engage their students

in a different and innovative way. They found that the authoring tool was really facilitating the process of creating their ILS. In general, they said that once they understood the process it immediately became user-friendly.

The most common issue was without question the lack of ICT infrastructure and support together with the lack of proper internet connection and time constrains. Language appeared very often as an obstacle. Students are not comfortable in general with the IB methodology. The process requires repetition and more instances of use in order to have the students really engaging in the process. Issues with localization were also mentioned several times.

When asked about preferred improvements to the system, the most common suggestions were related to language issues, the need for more published ILSs - in particular those addressing curricula content, to have provisions for slow internet connections, to add more labs, include more resources for primary schools, and better descriptions of labs and apps. The least appreciated aspect was the required time to create an ILS and the necessary time to properly implement and inquiry scenario.

Concerning their favourite features, participants named the repository of labs and apps, the support, the user-friendly way of sharing an ILS with students, the possibility of creating multidisciplinary scenarios, the user-friendly way to introduce inquiry and provide interactive and collaborative experiences to students whilst being users and finally, for teachers enjoyed being creators of new content.

6.5. Go-Lab user's behaviour

In the framework of Go-Lab there was a need to better understand the behaviour of the users to ensure the project would fulfil its main goal and reach students in classrooms. In other words, there was a need to understand what was necessary in order to ensure that teachers would really implement the project in classroom.

Table 6 presents an overview of the main indicators that have been used for our analysis. The period chosen for this study was from October 2014 to September 2015. The numbers presented are coming mainly from two sources, the weblogs of the system (Graasp) and the Google Analytics monitoring mechanism that tracks the use of the different components of the Go-lab system (Golabz portal, Graasp platform and Tutoring platform). A more detailed view of the analytics can be found in (Doran, Sotiriou, 2015).

Table 6 The key indicators for the Go-lab system use during the second phase of implementation (Oct 2014 – Sept 2015).

Schools	689	
Platform	Golabz	Graasp
Unique Users (google analytics – bounce rate removed)	18.000	5.000
Registered users (system web logs)	n/a	2461
Page Views	4.7/session	2.58/session
Average Time	05:09	06:21
Bounce Rate	38.1%	61.50%
ILS cloned and created		2459
New ILS with some activity (views of standalone view)		678

The strategy adopted, in the framework of the Go-Lab project, to measure the success of the community building strategy was to compare the data coming from both analytics and use it to quantify the optimal usage of the system. The following methodology was developed as a good measure of optimal use (Doran, Sotiriou, 2015):

- Based on the numbers of users of the Graasp platform (Go-Lab authoring tool) we made an estimation of the users who were making optimum use of the system. According to the data that is coming from the platform there were about **5000 active accounts** at the end of the referred period. These users have created an account but not all of them have proceeded to the creation of an ILS.
- The number of actions in the system (as measured by Graasp analytics) to represent the creation of a basic ILS is determined as 7, considering the most basic inquiry scenario with only 5 phases plus two hidden spaces (About and Vault).
- If we consider the creation of an account as 1 action, then the minimum number for a creator would be 8 actions.
- In this case if x, is the percentage of users performing 8 or more actions (creating account + ILS) and y the percentage of users that are performing 1 action (not creating an ILS) the total universe of users would be x + y =1.

Considering that:

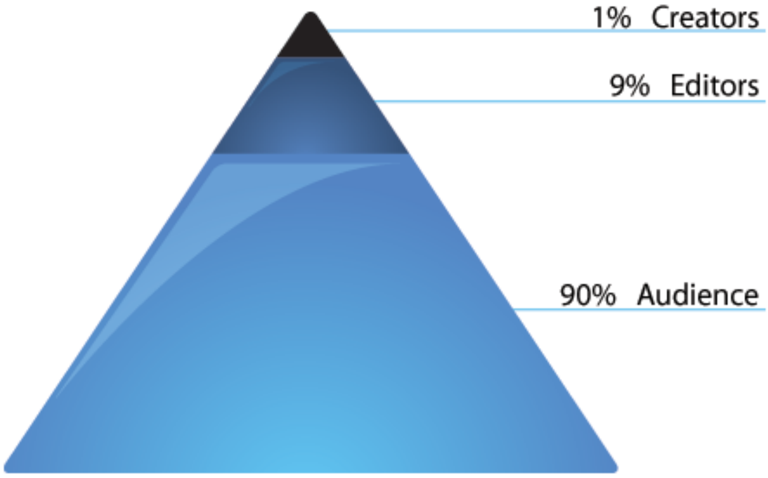
- there were 5000 active users from Graasp (accounts created in the system),
- that a good user (x) is the one that creates an account and a minimum of one ILS
- that a user that is not performing actions in the authoring tool only has associated to its actions the equivalent of one click

According to Graasp's data the users who have performed more than 8 actions on the platform are 1200.

Go-lab Users (more detailed in Table 6)

Using the portal (Google Analytics) (User Type A)	18.000 (100%)
Using Graasp (User Type B)	5.000 (28%)
Creating ILSs with Graasp (User Type C)	1.200 (7%)

Following the 90-9-1 rule for users participation in social media and online communities (McKee, 2009) we may claim that Go-Lab is performing very well.



(cc) Jake McKee & 90-9-1.com

Following the same approach, we are applying different filters (cut-offs) to the number of actions performed on each ILS so that we can make an estimation of the implementations that have been completed.

Our assumptions were the following:

- create an ILS – 8 actions
- Implement an ILS – 5 actions (when students use an existing ILS only 5 phases are used)
- 20 students access 5 pages = 100 actions
- Implemented ILS in a classroom with 20 → 8 + 100 = 108 minimum actions for classroom implementation

By applying the 108 actions filter we get 166 ILSs that meet this criterion (Set/2015). In most of Go-lab schools however the labs include less than 20 terminals, in most of the cases there are 10-15 terminals available for the project implementation. If we use the assumption that the number of terminals is 10 and accept that 10 standalone usernames is equivalent to 20 students being exposed to the use of an ILS the number we retrieve from the system is of 332 pilot implementations. Taking into account that about 700 schools were officially involved in the second phase of the project, with direct support from national coordinators, we can conclude that around 50% of them (teachers working in the Go-lab schools) have implemented ILSs in their classroom's lessons. These teachers have participated in engagement activities, training sessions, interacted with tutors and have received support from their national coordinators in order to achieve the present stage. These results are telling us that the approach proposed is effective. With the teachers support the systems were tested, suggestions implemented and adaptations to the support and training mechanisms carried on. On the other hand, if we consider all the users of Graasp we find that less than 7% of users of Graasp (332 at a global level) are using ILSs with their students. The number of potential users is calculated by assuming that each different nickname used to enter the student link is a different user or representing 2 students.

At the end of the project (Dec/2016) the number of schools associated to the project was 1047. The number of ILSs implemented, following the same reasoning above was of 678. This means that potentially 65 % of schools involved in the project had teachers implementing ILSs with their students. In Section 6.7 I present a more in-depth study that shows some evidence that the community building and support actions are key for a successful implementation of the project in classrooms. This study also shows growth from 50% to 65%, in accordance with what is expected from a project that is reaching its maturity and where teachers had the opportunity to get more experienced in IBL and its integration in the ILSs. Considering the data available in July 2018[39], using the analytics made available in the framework of the new project (Next-Lab) we see that the countries were a national representative was in place the number of implementers increased by 12% of the total number of registered users.

It is necessary to take into account that our baseline is the number of users searching the portal. The ones using the system are expected to do so soon after they explore the portal and get acquainted with the authoring tool. The 3rd level, the knowledge deepening, depends on the necessary time to build their own ILSs and to find an opening in the curriculum to implement it. Teachers are being trained in the use of tools and resources available in the portal, on the adopted pedagogical methodology (IBL) and to use the authoring tool (Graasp) to copy and create their own ILS. Many teachers have been involved in this process with different levels of commitment. Taking into consideration the time necessary for teachers to reflect on the use of their ILSs, to perfect them and make it relevant for the curriculum, it is expected that the number of implementers present will experience a slow growth at the beginning of the implementation run reverting that tendency on a later stage. Go-Lab is not the only project that requires such a journey for teachers, in fact, the shift towards a more student-centred model is what is requiring such a shift. Regardless of the complexity or simplicity of the tool presented, shifting from traditional teacher centred model towards a more

[39] Due to GDPR regulation it is not possible to present the full data here

innovative approach, advocating for 21st century skills, will always demand a shift of mindset, rarely an easy move. To support the professional development that is necessary for educators willing to take such journey we have developed a competence profile for teachers willing to shift from simple explorers towards proficiency in the use of method/system.

6.6. A competence Profile for teachers – from explorers to creators

Although this chapter is devoted to describe the creation of the competence profile developed for the project Go-Lab it is important to refer to other important documents that also create important profiles that are a reference for the professional development of every student. The first is the UNESCO ICT framework for teachers, arguably a central reference for other equally important frameworks (UNESCO, 2011) (Table 7)

The referred document was produced as a support action to accompany the integration of ICT equipment in schools and to maximize its use in benefit of the apprentices. The document intends to be a guideline to the construction of ICT competency policies and standards, and be an integral part of the ICT master plan of all nations. As it is stated in the second edition of this important document, in order to be prepared for the future challenges and accommodate innovation, societies need to:

- Prepare students for the world of work with the necessary skills to use ICT and handle information in reflective ways, with creativity and capability to use it to problem-solving and knowledge generation,
- To enable citizens to manage their own lives effectively and live full and satisfying lives,
- Encourage citizens to fully participate in society and be active members for its decisions, in particular when affects their lives.
- To enhance cross cultural exchanges and understanding in order to prevent and help solving conflicts.

The framework is not only about how to use ICT for teaching, it is much more than that. Teachers need to be confident in facilitating the use of ICT in order to be able to integrate in their practice technology enhanced learning (TEL). They need to be able to integrate ICT as a tool to foster key competences in their students such as: collaboration skills, problem solving, creativity through the use of ICT and other important skills. This will help them become better informed and hopefully better citizens, informed members of the workforce with key social and human skills. The framework addresses the following topics:

- Understanding ICT in education,
- Curriculum and assessment,
- Pedagogy,
- ICT,
- Organization and administration,
- Teacher professional learning.

The framework accommodates three different levels of competence profiles. The first level is attributed to the teachers that have Technology Literacy. This is the first stage and the minimum necessary to facilitate its use. The second level is Knowledge

Deepening, where students, via using ICT, acquire the competences that are necessary to have a deeper understanding of the themes being presented and can use them to solve real-world problems and transfer the knowledge to multiple different situations. The third and more challenging one is the Knowledge Creation, where end users become able to create new knowledge for the benefit of the societies they belong.

Table 7 UNESCO ICT competency framework for teachers

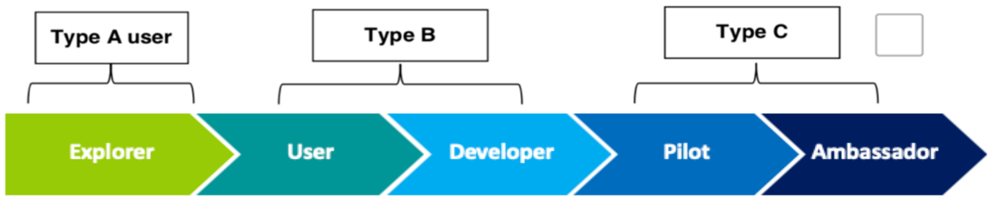
THE UNESCO ICT CMPETENCY FRAMEWORK FOR TEACHERS

	TECHNOLOGY LITERACY	KNOWLEDGE DEEPENING	KNOWLEDGE CREATION
UNDERSTANDING ICT IN EDUCATION	Policy awareness	Policy understanding	Policy innovation
CURRICULUM AND ASSESSMENT	Basic knowledge	Knowledge application	Knowledge society skills
PEDAGOGY	Integrate technology	Complex problem solving	Self-management
ICT	Basic tools	Complex tools	Pervasive tools
ORGANIZATION AND ADMINISTRATION	Standard classroom	Collaborative groups	Learning organizations
TEACHER PROFESSIONAL LEARNING	Digital literacy	Manage and guide	Teacher as model learner

This framework isn't, of course, all that is necessary, it is just one step in the preparation of educators to uptake the role of facilitators of the future rulers of this planet. They will also need to become skilful designers of learning environments and capable of integrating innovative pedagogies while making full use of ICT as the tool to deliver it (Paniagua & Istance, 2018). In the same document the role of school networks is highlighted as a crucial source of support for educators, as already highlighted in this document. The need for interdisciplinary learning and assessment of students while using student centred methodology are also key points. These are addressed in the next chapter when the WIIL methodology (Working with Inquiry and Interdisciplinary Learning) is presented (Doran, P., Doran, R., *in prep*.). Collaboration among teachers has proven to be positively associated with the performance of students in science (OECD, 2018e), which is understandable as it provides opportunities for horizontal, vertical and diagonal articulation besides a proper contextualization of learning.

The competence profile presented in Table 8 Competence Profile of Go-Lab Users tries to accommodate all these components while integrating a few particular steps that are localized for the specificities of Go-Lab.

Table 8 Competence Profile of Go-Lab Users



Using the Go-Lab environment	Get acquainted with Go-Lab portal and the ILS model	Explore and adopt some ILS	Create their own ILS	Implement ILS with their students	Train others
ICT Skills	Basic ICT skills	Acquainted with the use of online labs and simulations	Capable of developing online lessons and create metadata	Skilled in the use of ICT, in the creation of learning scenarios, etc.	Capable of sharing their expertise with others
IBSE experience	New to IBSE	Some experience in student centred teaching	Has experience in the IBSE model	Skilled in using the IBSE model with students	Master IBSE and is capable of introducing others to the concept
Online / Remote Labs	Integrate some labs in their lessons	Integrate ILS in their lessons	Develop ILS and pilot test them	Integrate the use of ILS in several lessons	Support other teachers to implement ILS in their classrooms

This profile was created to help us understand the different possible paths a Go-Lab teacher could take and define the necessary steps to bring educators from the initial stages to the accomplishment of their full potential (Doran & Sotiriou, 2015). The successful implementation of Go-lab and its continuation, as presented in this document, shows evidence of the impact of an effective mechanism to prepare and support teachers to fully join Go-Lab. Teachers can have several levels of proficiency, starting from simple explorers with basic ICT skills to those that have enough digital skills to support others willing to join the project. In the Users section we present a schematic view of the different profiles of potential users, developed and pilot tested in the framework of the project. By matching the different engagement activities with the behaviour of the users we can explore some possible outcomes:

- Dissemination events functioned as trigger events for visits to the Go-lab portal. The first level of users emerge from here: Explorer
- The visionary workshops motivated the next level of engagement where visitors became Users of the system
- Training events were the most effective mean to promote users to the next level - Developer/Creator of resources
- The continuous support provided by national coordinators and by the pedagogical and technical teams were the key aspect for the emergence of the next level of engagement, the Pilot implementers of ILSs
- Finally, the continuous contact and further training to the same teachers empowered many to start training others, reaching the level of ambassadors.

A large population of teachers engaged in different levels of interaction and use of the system.

Using our analysis, we were able to collect evidence of different levels of Go-Lab teachers participating in the project and to what extent we managed to support their development to the level of ambassadors. Training courses promoted at a national level and international gathering events such as the summer schools were key to improve their competence profile to the maximum extent. Their path can be summarized as follows (Mavromanolakis & Doran, 2016).

- **Explorers** – Visitors exploring the collection of online labs, published ILSs, apps, etc. (Usually participants of Visionary Workshops and/or dissemination events);

- **Users** – Registered members of Graasp that are somehow using the system by copying and/or repurposing an existing ILS or creating a new one. (Usually participating in training events and/or using the support facilities available at Golabz);

- **Developers/Creators** – Those from the above category that further explore the system by creating ILSs that follow the "Good ILS standards". Meaning, ILSs that include an effective inquiry methodology, contain labs and apps, etc. (Usually participating in training events and using the support facilities available at Golabz);

- **Pilot Implementers** – Some of the developers reach the mature stage where they are now capable of implementing ILSs with the students. (Usually participating in training events, practice reflection workshops, pilot's days and demo activities in schools);

- **Ambassadors** - The highest stage that contemplates those that are already in a position to train other teachers and promote the development of collaborative instances (These teachers are often participating as tutors/supporters in engagement activities and training events).

The summer schools and the national training events were used as a space where we could gather valuable information from the participants and continuously improve the system accordingly. Teachers participating from the very early stages were key to the success of the project but also evolved in their professional development while supporting Go-Lab. These examples were considered validators of the strategy developed for this project. The profile had several indicators to validate the strategy and commitment of the teachers involved in the process. In (Figure 93) we can see evidence of the commitment of the teachers involved in the project during the school's years 2014/2015 (only tracking teachers) and 2015/2016 (tracking teachers and students).

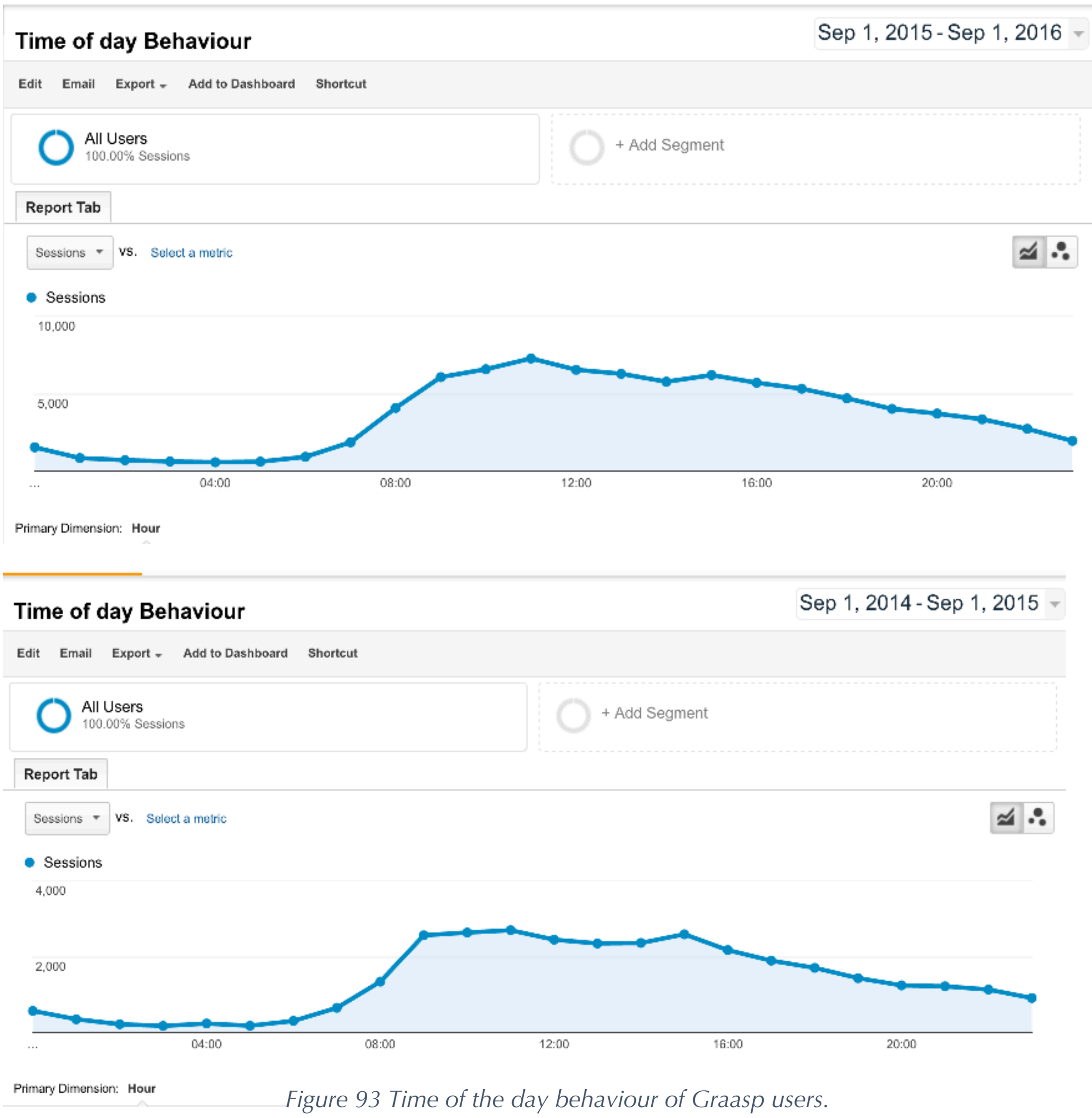


Figure 93 Time of the day behaviour of Graasp users.

The time of the day when the system has a peak of use, from 08:00 to 17:00, is probably taking place during school hours. In the bottom panel of the figure numbers refer only to teachers using the system, while the upper panel also includes students. We can also see that the system is being used beyond school hours, in the previous phase by teachers, probably while preparing their ILSs.

Overall, these numbers are very encouraging as they are indicating the level of commitment of users that are progressively exploring the system more in depth and taking Go-Lab into their classroom settings.

6.7. Impact of the proposed framework for community building and competence profile

As a next step, we investigated the impact and differences in the creation and implementation of ILS with a given number of stand-alone users (potential students) between the countries where the full Go-Lab Community Support Methodology was applied (i.e., Go-Lab countries) and those countries where mainly the online support was available (i.e., non-Go-Lab countries). We also investigated the impact of the summer schools and a pilot study in one of the Go-Lab countries, Portugal.

6.7.1. The example of Portugal

According to Google Analytics this was the distribution of users of Graasp across the country (Table 9).

Table 9 Distribution of users across the country according to Google Analytics

Region	Sessions	% New Sessions	New Users	Bounce Rate	Pages / Session	Avg. Session Duration
Setubal	6,353	28.81%	1,830	22.46%	10.12	00:12:52
Lisbon	3,697	34.16%	1,263	23.59%	12.31	00:11:45
Porto District	1,285	33.93%	436	15.33%	18.37	00:14:56
Aveiro District	947	29.99%	284	8.98%	14.61	00:15:39
Madeira	883	29.11%	257	26.50%	20.12	00:15:45
Santarem District	276	60.87%	168	19.93%	12.21	00:11:30
Faro District	262	46.18%	121	17.18%	11.13	00:09:24
Viseu District	175	40.00%	70	44.00%	3.21	00:09:06
Vila Real District	140	19.29%	27	18.57%	19.93	00:16:18
Braga	127	51.97%	66	18.90%	7.94	00:04:34
Leiria District	94	40.43%	38	15.96%	10.26	00:07:19
Coimbra District	82	58.54%	48	19.51%	5.23	00:03:40
Azores	32	28.12%	9	62.50%	1.91	00:02:13
Guarda District	30	73.33%	22	20.00%	7.27	00:07:09
Castelo Branco District	29	58.62%	17	20.69%	6.38	00:05:30
Viana do Castelo District	20	70.00%	14	10.00%	12.5	00:10:04
Portalegre District	19	57.89%	11	26.32%	3.21	00:04:14
Beja District	11	45.45%	5	27.27%	5.27	00:03:03
Evora District	8	50.00%	4	0.00%	8.38	00:08:13
Braganca District	7	85.71%	6	0.00%	3.57	00:00:35
(not set)	2	50.00%	1	100.00%	1	00:00:00
	14,479	32.44%	4,697	21.53%	12.29	00:12:47

Portugal was the country with more teachers participating in training events (Figure 94). In total, during (2012-2016), 452 teachers attended training workshops. Most of them participated in the course accredited by the CCPFC. These teachers came from 180 schools distributed across the country.

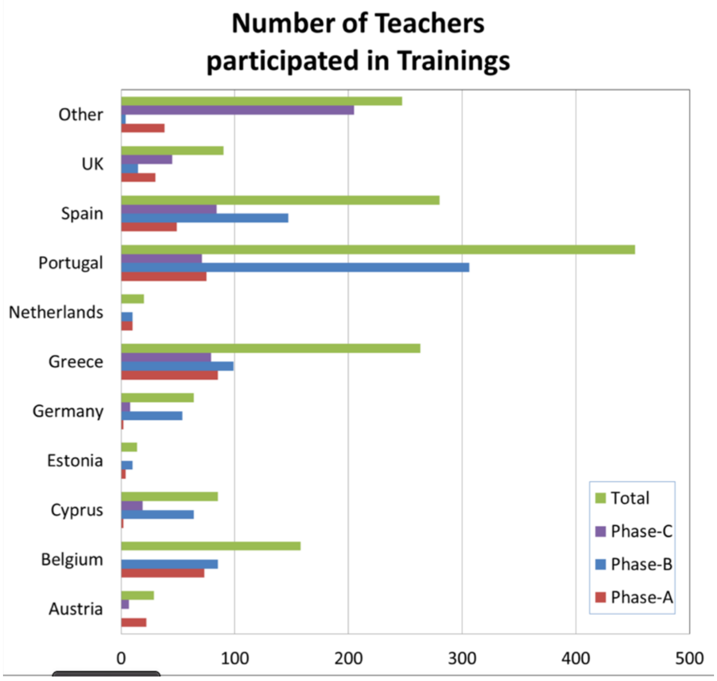


Figure 94 Nº of teachers that participated in training events per country (from Mavromanolakis & Doran 2016).

Portugal was one of the countries with the larger percentage of teachers implementing their ILSs in instances with more than 10 standalone viewers (assumed to be students). Since in Portugal and in fact in most of the partner's countries, computers tend to be shared by 2 or 3 students, thus we assumed that 10 standalone viewers would be a fair number to identify classroom implementation instances. The other country with a good percentage was Cyprus, where all the implementers also received training (Table 10).

Table 10 Table of creators and implementers per country (Data from Jan 1st, 2017)

	Nº of users registered in Graasp	Nº of creators	%Creators	Nº of potential implementers (>5)	Nº of potential implementers (>10)	% of implementers (>10)
Cyprus	107	93	87%	24	17	16%
Estonia	407	322	79%	43	29	7%
Finland	62	43	69%	2	2	3%
France	235	50	21%	9	9	4%
Greece	233	155	67%	33	24	10%
Netherlands	361	284	79%	44	37	10%
Portugal	282	223	79%	60	36	13%
Spain	637	471	74%	52	45	7%
United Kingdom	189	154	81%	13	10	5%

In Table 11 we present the overall number of registered users in Graasp, the total number of authors, those that created at least 2 and those that have created more than 10 ILSs. If broken down between partner countries and non-partner countries, summer school participants and the particular case of Portugal trained and non-trained teachers, we get the results shown in table 11 (To be noted that this study was conducted in July/2016 and doesn't include all the registered participants, trained teachers to date). After this date, due to data protection issues, access to the data was no longer granted.

Table 11 Behaviour of different users in terms of creation of ILSs and implementation.

(October 2014-July 2016)		Authors (= creator of ILS)		Authors of 1 ILS		Authors of 2 to 10 ILS		Authors of more than 10 ILSs		Implemented with more than 5std		Implemented with more than 10 std	
Registered Users in Graasp		nº of Aut.	% of users	nº of Aut.	% of users	nº of Aut.	% of users	nº of Aut.	% of users	nº of Impl.	% of users	nº of Impl.	% of users
All	4.940	3.323	67%	1.622	33%	1.540	31%	161	3%	331	7%	245	5%
Go-Lab countries	2.913	1.840	63%	751	26%	960	33%	129	4%	296	10%	215	7%
Non-Go-Lab countries	2.027	1.483	73%	871	43%	580	29%	32	2%	35	2%	30	1%
Summer School	90	87	97%	14	16%	47	52%	26	29%	50	56%	46	51%
Portugal (not trained)	157	105	67%	40	25%	65	41%	0	0%	11	7%	5	3%
Portugal (trained teacher)	125	102	82%	47	38%	50	40%	5	4%	34	27%	16	13%

The numbers presented are not enough to allow a more profound, analysis and a larger fraction of the system users would have to be analysed in order to allow a stronger conclusion. However, the results are in accordance with the view presented in this document that teachers receiving training and support are more likely to implement their ILSs with their students. The identification of the country of the different users was done based on data retrieved by the system. This means that the country associated with the different users was the country where the users presented a larger number of actions. This was not necessarily the correct association. In order to better understand the data, and in particular related to the teachers that presented a larger number of standalone users, supposedly students, some cleaning of the data was conducted. The sample of implementers was individually checked, and their assigned countries corrected. This was done in order to ensure teachers from other countries, outside the partner countries, were not part of the sample selected for a more in-depth study (summer school and Portugal). Special attention was given to participants coming from Portugal where we could easily identify those that received some sort of training given by the national coordinator or identified ambassadors.

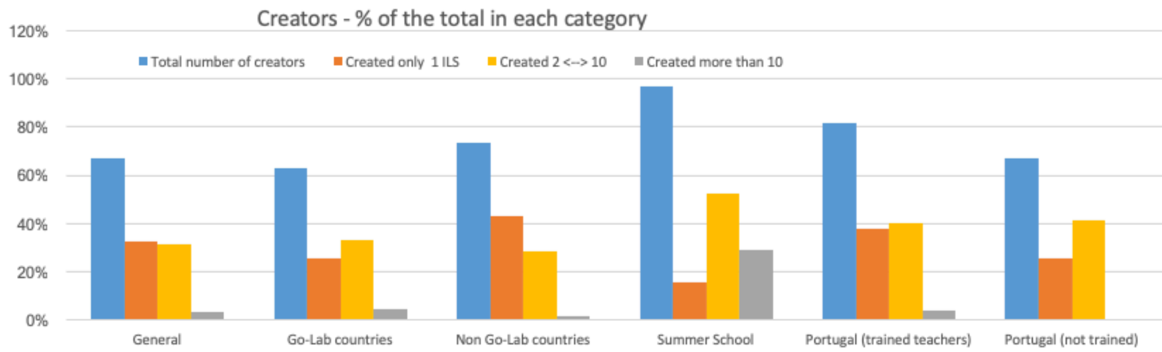


Figure 95 Comparison among creators of different groups

The data shown in Figure 95 show some indication that teachers from partner countries present a tendency to create a larger number of ILSs, but the effect of community building activities are more evident in the summer school participants, in general they created far more ILSs, in percentage, than the other studied groups. In the case of the Portuguese teachers we find an interesting result where the not trained sample creating 2 to 10 ILSs is larger than the number coming from the trained teachers. However, trained teacher also had a percentage of creators who went beyond the creation of 10. These results indicate that the system is mature enough to support teachers that are not reached by our training efforts as national coordinators. In this case, the support provided by the platform is enough to encourage the copy, creation and repurposing of ILSs.

The case changes slightly when we study the number of implementers as also shown in Table 11 and Figure 96 where we present the comparison of the implementation rate among the different categories, the general non-identified user, users coming from partner countries, users coming from non-partner countries, participants of the summer school and users from Portugal (trained and not trained).

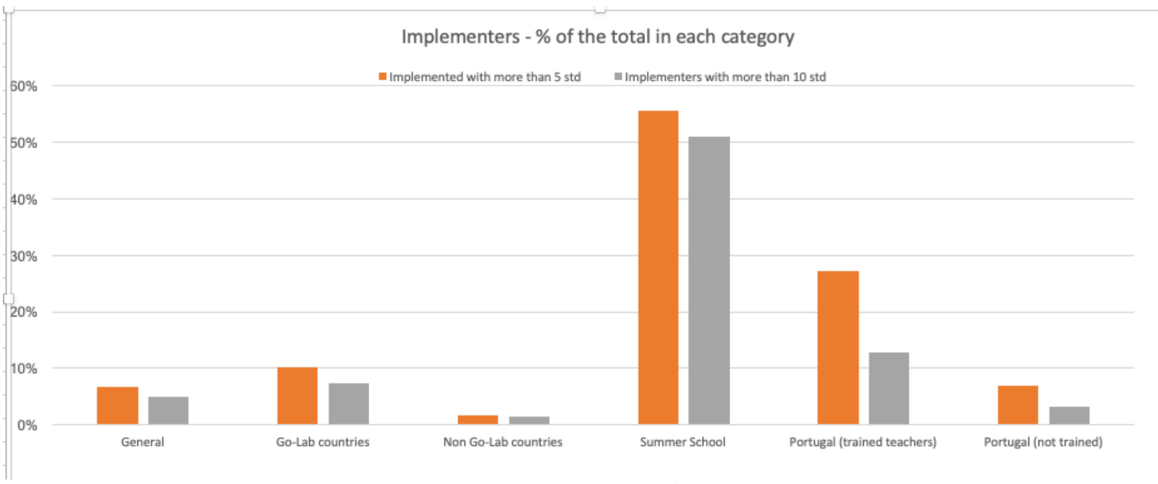


Figure 96 Comparison among implementers per category

As before, in partner countries teachers showed a higher rate of implementation of ILSs than in non-partner countries. It seems that those teachers and authors who were engaged in the Community Support Activities in Go-Lab countries had a higher success rates in bridging the gap between ILS creation and implementation. Participants from training events (summer school and training in Portugal) showed the highest level of implementation, in relation to those who did not participate in a training event. The numbers are not enough to allow us to present a prediction that there was a causal effect but certainly, having a direct contact with peers and being able to discuss the creation and implementation of ILS in a workshop is likely to lead to a significant higher rate of authors that are actually implementing the ILS they created.

We can therefore with some caution consider that the physical workshops and/or the personal contact of Go-Lab partners with participants might have a direct quantifiable positive impact on the implementation of their created ILSs. There are for sure some selection bias in the data since the participants of some of those teachers of the Go-Lab contests (that received as a prize the participation to the summer school) had as a requirement that their submission should be the result of an implementation instance. The interesting fact is that they implemented much more than what was required. Also, there is a large fraction of participants of the summer school that prior to participating in the contest were already trained in their countries. For the case of the Portuguese trained teachers there was no such requirement and yet there are several cases of multiple implementation instances.

A full analysis of these results is presented in the study made by (Mavromanolakis & Doran, 2016). Also, it is important to note that the Graasp system does not require users to identify their country of origin, therefore, the analysis done with its numbers should be considered with caution. In order to understand the retrieved data a careful organization and validation process, confirming, the country of origin of the user and ensuring there was no repetition of data from participants who changed groups (i.e. non-trained teachers that created ILSs and later on received training) was performed.

Although more studies would be required to support these assumptions it is nonetheless a good indication in the direction of the hypothesis we are testing. Face-to-face training workshops and personal contact with Go-Lab partners might be the one factor that is motivating and empowering teachers to create more ILSs and finally implement them with their students. We can speculate and summarize a few important findings, relevant to this paper (Doran et.al., submitted):

- In partner countries, where the Go-Lab Community Support Framework & Methodology was fully implemented, better results were achieved related to the creation and implementation of ILS, compared to non-partner countries;
- The data analysis (shown above) presents evidence that face-to-face training workshops and other events (such as the summer school) were an important positive factor in the teacher's engagement in the creation and implementation of ILSs;
- Creation and implementation of ILSs was also achieved in non-partner countries as well as in countries where no direct support was available. One important factor influencing this could be the online-based support infrastructure which offered supporting activities throughout implementation, such as MOOCs, Support page, Forums, etc..
- These results reflect the challenges and constraints faced by teachers in implementing ILSs in their school. Without ongoing or direct support, it seems to be more difficult to introduce Go-Lab into the classroom.

The main user data allows us to draw the following preliminary results:

- Overall user numbers of the Go-Lab system are significantly higher (65.59%-20.89%-12.43%) than the 90-9-1 model predicts in both Go-Lab countries and non-Go-Lab countries;
- In countries where the Go-Lab Community Support Framework & Methodology was fully implemented, better results in the creation and implementation of ILS were observed compared to non-Go-Lab countries;
- Since many of the support tools and activities were online, there is a strong evidence that physical (training) workshops and other events (such as summer schools) made pivotal difference in the creation and implementation of ILSs;
- There is evidence that physical events together with the direct contact to Go-Lab partners lead to a higher creation and implementation of ILSs and are therefore more efficient and effective than the online-based support activities (e.g. MOOC, Support age, Forum, etc.). It seems that whenever a user was involved in a Go-Lab partner country, the direct support, the continuous personal contact, resulted in more created and implemented ILS;

This result also reflects the challenges and constraints faced by many teachers in implementing ILS in their school. Without ongoing or direct support, it seems to be more difficult to introduce Go-Lab into the classroom. A total of 6517 users and 3877 authors were recorded in the Graasp system, while only 1.692 teachers were trained in physical or virtual workshops. This has to be understood as one of the main achievements of the Community Support Activities. Only the activities of "Community Building" can explain that for every teacher trained in a physical workshop ➔ 4 non-trained users have registered to Graasp, and ➔ 2,29 non-trained users have become authors.

Overall, the factors contributing to the different usage of the Go-Lab system are influenced by a variety of different causes. Taking into account that training teachers on the use of the system requires time for practicing, reflecting and adapting to the curricula, we have to note that the presented numbers have exceeded our expectations by far. The different activities conducted supported the professional development of teachers. The distribution across the different levels of the competence profile can be seen in Table 12.

Table 12 N° of teachers in each category of the competence profile

	Total number	Percentage
Explorers (100% of users)	48.902	100%
Users (registered to Graasp)	4.940	10.1%
Developers/Creators (of an ILS)	3.323	6.8% of Golabz explorers became creators 67.5% of registered users to Graasp became creators
Pilot - Implementers (with more than 5 std users)	331	0.67% of Golabz Explorers became pilot implementers ~10 % of creators became implementers

6.8. Summary and key indicators of the school pilot phases

6.8.1. Go-Lab Summary (2014-2016)

Besides the multiple dissemination activities performed throughout the project, a series of implementation activities were also conducted. These involved teachers and students reaching a large audience across the partner countries. Following closely the implementation and professional development strategy, schools were officially involved, teachers and students actively engaged in the multiple opportunities. A summary of the project from October 2014 to July 2016 was presented in (Mavromanolakis & Doran, 2016). Below are listed the main key quantitative and qualitative indicators achieved.

- 1692 teachers from 1041 schools attended the training workshops that partners organized;
- 4283 students from 218 schools participated in the activities that partners organized;
- 4940 new users registered from Oct 2014 to July 2016;
- One third of the registered users directly participated in the reported training events. From these, as presented in Table 11, 67% actively used the authoring environment to create their own ILSs;
- More than 300 ILSs were implemented in schools reaching more than 4200 students.

In Portugal the total number of teachers that participated in training activities (short and long duration) was over 450. From those, 125 participated in accredited trainings by the CCPFC, until July 2016. The number of students reached was over 666 coming from 180 different schools. There was a good geographical distribution as can be seen by the Go-Lab analytics presented in (Figure 97).

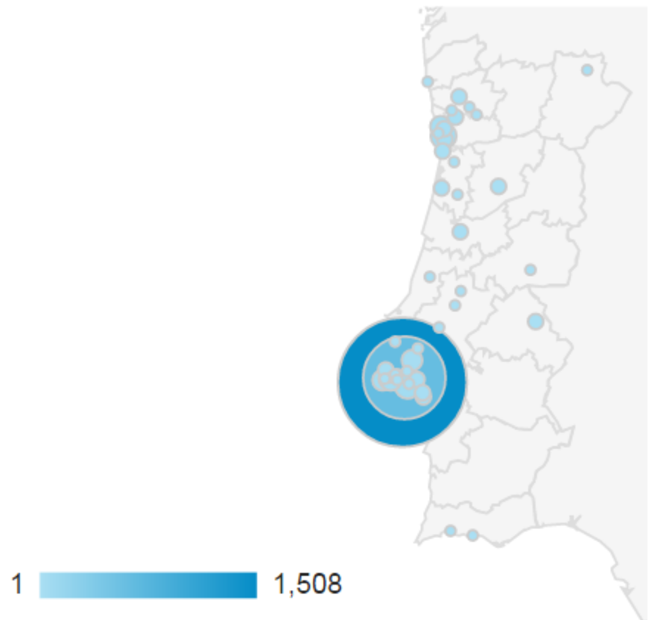


Figure 97 Distribution of Go-Lab users in Portugal until July 2016

6.8.2. Next-Lab Indicators (Jan/2017 – May/2018)

In the framework of Next-Lab a new strategy was put in place in order to allow better tracking of users and ensure that the European General Data Protection Regulation (GDPR) was in place. All event participants, mostly events devoted to train participants in short- or long-term activities, were invited to become members of communities of practice.

By to May/2018 the number of registered users, allowing tracking of their data for the purpose of research, were 1900, coming from NECs (National Expertise Centres, project partners) and Ambassadors activities (within and outside member countries where the NECs and Ambassadors were established). These indicators were very useful to further test our assumption that trained users are more likely to implement their ILSs than non-trained users. Using the numbers provided by Graasp analytics we had concrete information.

In May 2018 we had 12.382 creators of ILS with evidence of 833 implementations (~7%). From those creators, 231 were registered to the Go-Lab new community services. All of them had participated in training events (short and long duration). From those nearly 80 (35%) created more than 1 ILS and over 35 implemented their ILSs in classroom, 15% of the users registered to the community. This is 4% of the total implementation runs from the project (833 implementations).

In May/2018 Portugal had 682 teachers as registered users to Graasp (not all of them integrated in the community). Over 70% of them are active users of the system and from these, 445 are creators of ILSs, 60 (~9%) are implementers with more than 10 students, in comparison to the Portuguese users or 7% related to the total number of implementations. They have generated in total 3560 standalone users.

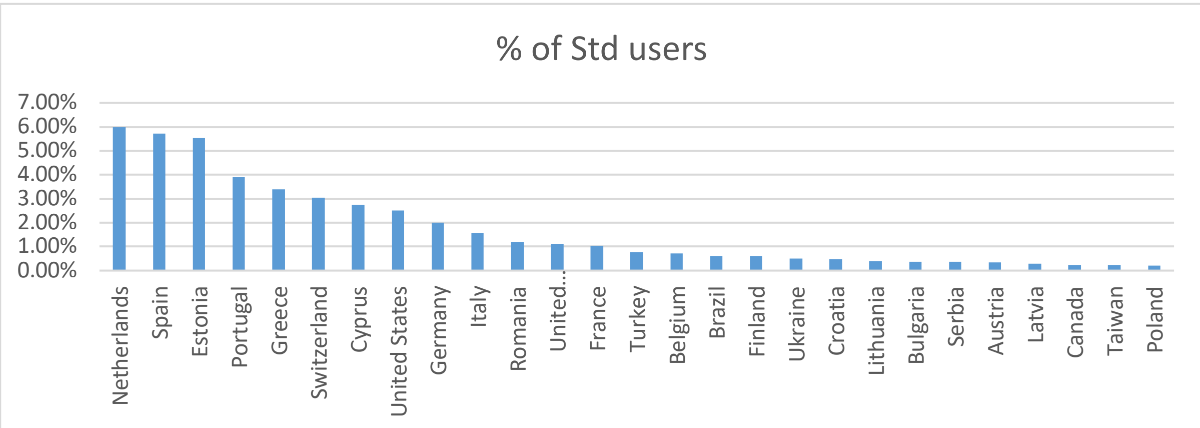


Figure 98 % of the total number of students reached by each country

If we compare Portugal with other countries where the project has a national representative (NEC – National Expertise Centre) we can see that Portugal is performing very well (Figure 98) in terms of numbers of students reached and also in numbers of creators and implementers in the different countries (Figure 99) and (Figure 100).

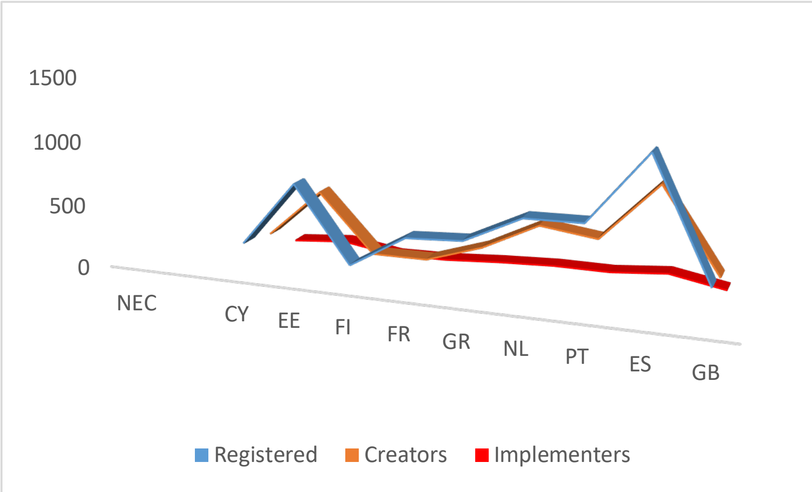


Figure 99 Comparison of number of creators, and implementers across the different countries (partners of the project)

For the school year of 2018/2019 a series of training courses are foreseen at a national level and as a result we expect an increase of the indicators.

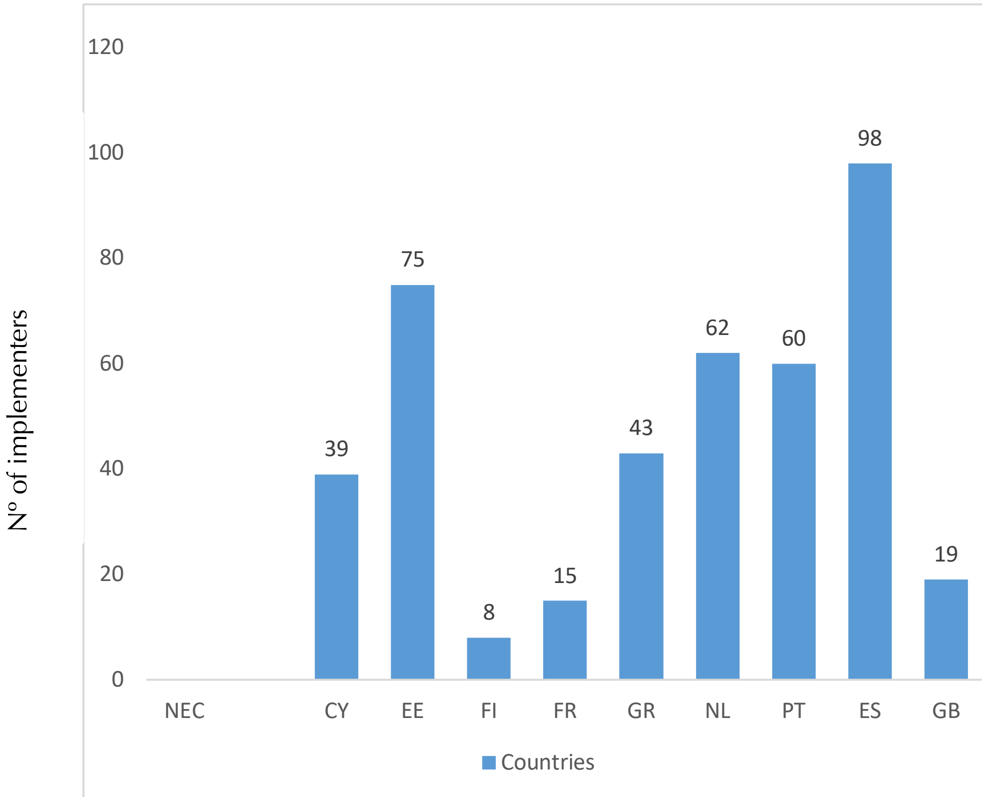


Figure 100 Comparison of the nº of implementers per partner country

Portugal reached over 5700 students during the classroom implementation runs. A very good number considering the general reach of the project (Figure 101). This was equivalent to 4% of the total number of students reached by the project.

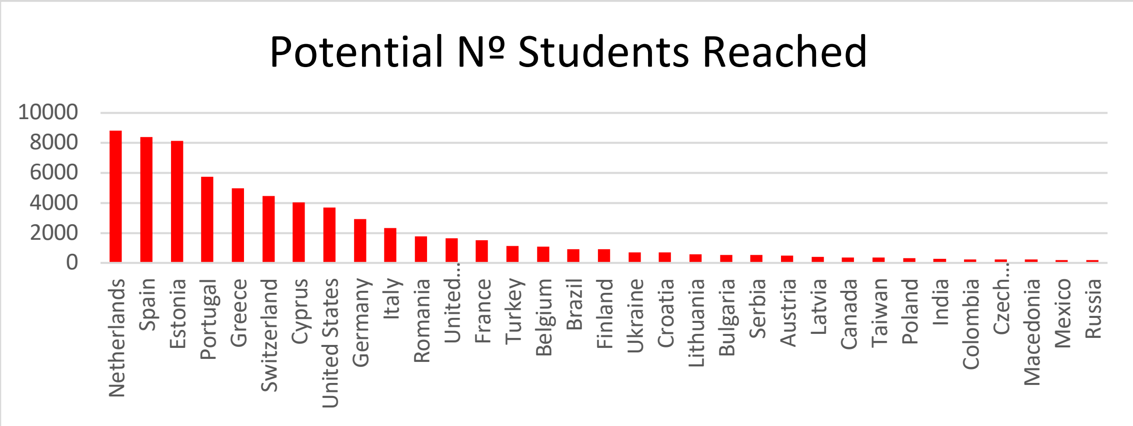


Figure 101 Absolute nº of students reached per country (May/2018)

The number of implementations is steadily growing, which is expected as users become more proficient in the usage of the system and new users are coming on board. With a quick comparison between the performance of the different communities we can retrieve a few interesting results (Table 13):

Table 13 Updated numbers retrieved from the system (May/2018)

		Whole World		NEC		AMB		Portugal		Whole World Excluding NEC and AMB	
Explorers	Retrieved from Google Analytics	139125	100.0%	34286	100.0%	20485	100.0%	3906	100.0%	84353	100.0%
Users	(registered to Graasp)	23819	17.1%	5013	14.6%	4863	23.7%	682	17.5%	13943	16.5%
Developer	(Creators of ILSs)	12382	8.9%	3483	10.2%	2021	9.9%	445	11.4%	6878	8.2%
Pilots	(Implementers)	833	0.6%	419	1.2%	257	1.3%	60	1.5%	157	0.2%

In terms of countries, with at least 1 user registered in the authoring tool, NECs are representing 9 countries, ambassadors are representing 19 countries. and the rest of the countries presenting some users are 122 countries.

The Go-Lab portal received visitors from all over the world. The number of Explorers, visitors of the Go-Lab portal, was retrieved from Google Analytics. We can see a very impressive growth when compared with the 18 000 that we used for the study presented previously (referring to Phase A of the project first year). The project dissemination is in good health and more and more users are being attracted to the project. The majority of Explorers (Figure 102) tend to stay at this stage as simple visitors or users of the many online laboratories available in the presented collection. In Dec/2018 the number was of 574 (52 remote labs, 505 virtual simulations, 17 data sets).

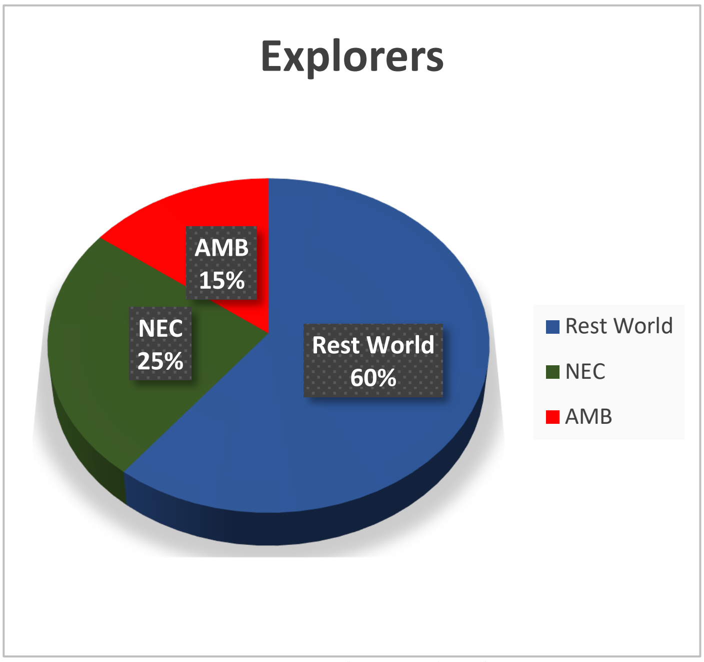


Figure 102 Distribution of Explorers

From those, over 17% (23.819 users) became users (Figure 103) of the system, those that register to Graasp, the Go-Lab authoring tool, exhibiting some interest in getting to know better the available infrastructure. The distribution, in percentage, between NEC, Ambassadors and the Rest of the World is not very different. The presence of a national representative does not make a huge difference in terms of generating potential users of the whole system.

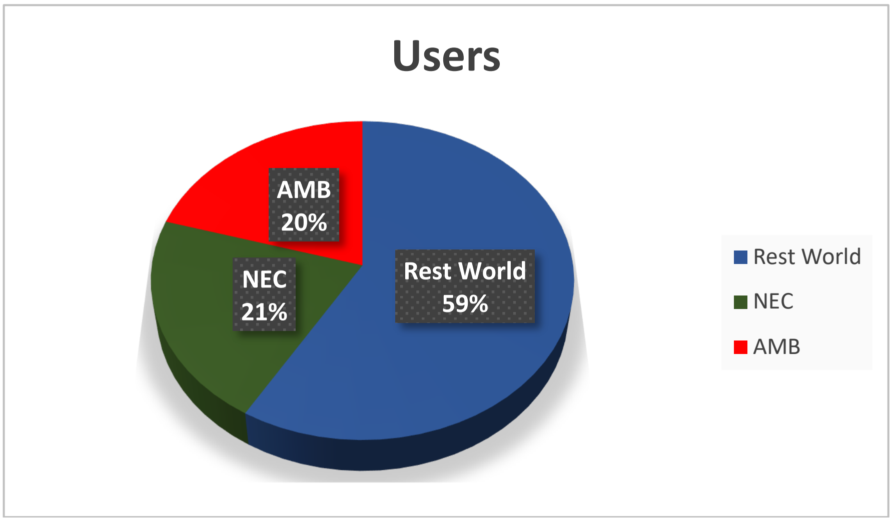


Figure 103 Distribution of Users

Over 8% of the explorers became developers (Figure 104), i.e., creators of Inquiry Learning Spaces. Again, a similar distribution to what we have seen before. In total 12.382 explorers became creators of ILSs at a global level.

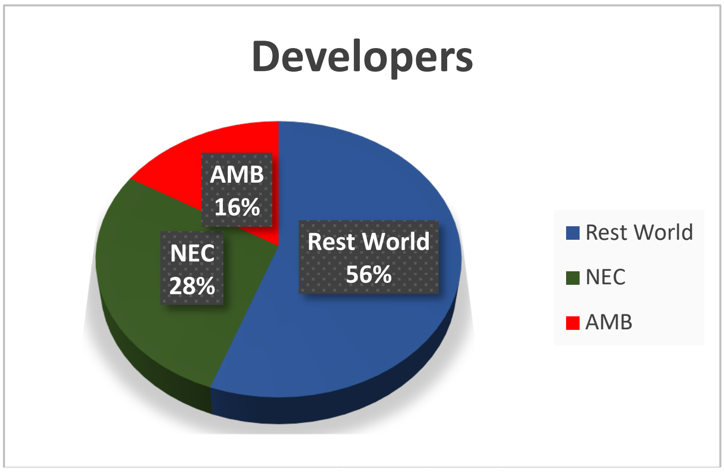


Figure 104 Distribution of Developers

The success of the project relies on actually reaching out students. We knew from the beginning that the overall proposed methodology and ecosystem was going to require some effort from promoters and some exploration time from users in order to finally reach the students. It was necessary to overcome several barriers, as already described in this chapter, some related to infrastructure, some related to the competence profile of the teachers, some related to national policy, to name a few. The number of implementers (pilot teachers) (Figure 105) is steadily growing and in May/2018 this number reached 833 implementers. Here is where we see the importance of having a national representative investing in the development of the competence profile of the teachers in their communities. While NECs and Ambassadors reached a large number of implementers, 81% of the total number of implementers, the rest of the countries presents a much lower percentage. It provides further evidence around the importance of the existence of local support as a trigger of full implementation instances.

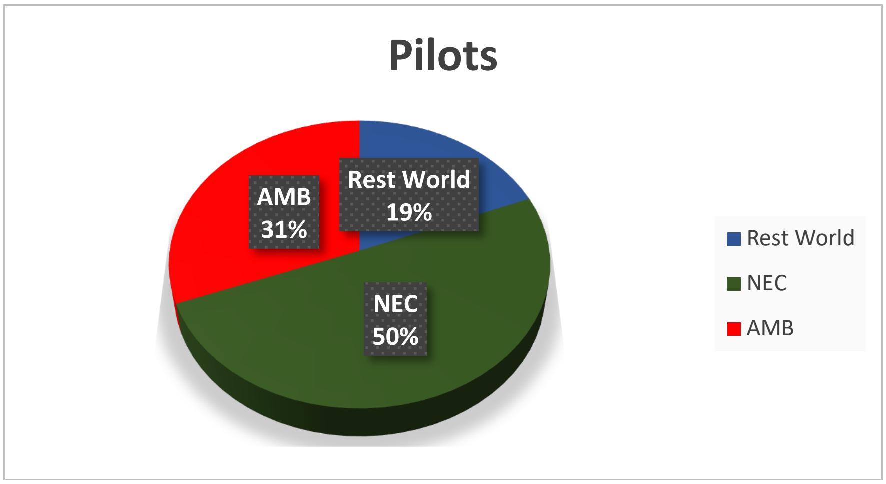


Figure 105 Distribution of Pilots

As mentioned previously, teacher training events are taking place since the very beginning of the project. In Portugal for instance, over 300 teachers have been reached directly by our training events and others are now being reached by the many ambassadors emerging all over Portugal, the so called pilots projects. The Communities of Practice (COP) are a new feature available since January/2017. Nonetheless, as an exercise we decided to compare the number of implementers we find inside the COP. If we consider the whole universe of creators, we see that those that are members of COP are implementing more than the rest. Still worth mentioning that many of the remainder implementers, not part of COP might have been trained in the framework of Go-Lab. In (Figure 106) we see the number of creators coming from the whole world (several creators and very little implementers), the National Coordinators, ambassadors and communities. Clearly the members of COP are performing better.

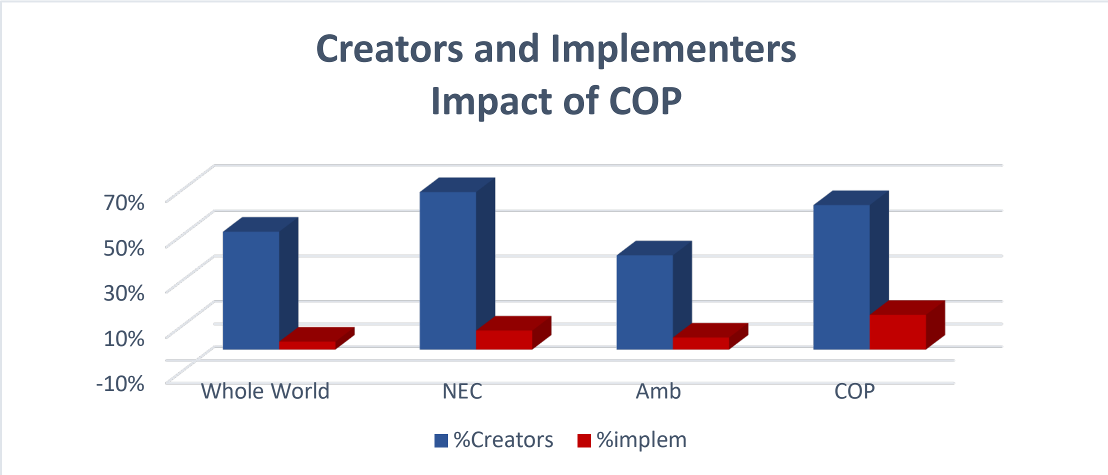


Figure 106 The impact of the COP

Although we can't prove that the training is fundamental if we want to see innovation reaching the classroom practices, we have some compelling evidences that this vision is indeed a reality.

6.8.3. Success stories from Portugal

The Portuguese national coordinator (NUCLIO) is a certified training centre in Portugal and who has successfully managed to accredit a course devoted to Go-Lab. The course was repeated in several parts of the country, including one of the islands. Teachers participating in the course were able to receive 1 credit, a minimum they need to earn every year in order to progress in their career.

Besides this important accreditation model, NUCLIO celebrated an agreement with the Ministry of Education that formally endorses Go-Lab for the quality of its tools, resources and methodology.

César Marques who is a teacher in a vocational school in Portugal, participated in Go-Lab activities from the very beginning of the project. In a recent online talk his trajectory was revisited. César perfected his skills in the use of IBL and started using Go-Lab for most of his lessons with his students. He successfully trained Luis Esturrado. Luís created 48 ILSs (of which nine were published at Golabz) and implemented them with more than 100 students in various classrooms.

César was a very active teacher and created over 100 ILSs and helped perfect the authoring tool. He is now keen to explore the multidisciplinary possibilities using Go-

Lab and wishes that more teachers in Portugal would share their ILSs so that topics of the curriculum would be well covered, and exchange of good ideas could take place. They both claim that the biggest obstacles were overcoming their own fear. During the last school year César presented his work in Go-Lab in several national and international events.

Marília Peres got in touch with Go-Lab during a visionary workshop conducted in Portugal. She participated in the Go-Lab summer school in 2015 and learned for the first time how to use the system. Her school only has one computer room which made it difficult to implement Go-Lab. She found the perfect solution, she could request the library room, where some computers were available, and implement Go-Lab there. She successfully created 27 ILSs (three of them published in Golabz) and implemented them with over 177 students. The impact on the students, according to the view of the teacher, was significant, they completely changed their attitude towards science. Following this success, and being a certified trainer in Portugal, she accredited a Go-Lab course and promoted it to teachers in her school cluster. **Marina Balbina** was one of these teachers and later on she created 8 ILSs (three of them published in Golabz) and implemented them with 26 students. She applied to the Go-Lab contest and was one of the participants of the Go-Lab summer school in 2016.

Álvaro Folhas joined the Go-Lab project as a teacher in the very beginning during the pilot stage. He mastered the use of the system and guided many students in the use of ILSs. In 2016 Álvaro's students took part in a scientific campaign promoted by the UK partner in the framework of a Go-Lab activity and supported the team in Cardiff to build the light curve of a recently spotted supernova (Figure 107). His numbers: 16 ILSs and 81 students.

Figure 107 Image taken by Álvaro Folhas and his students with the Faulkes Telescope

This report has shown that teachers - for the most part - appreciated and felt they needed the direct and physical support of Go-Lab partners to learn about meaningful ways to make use of the Go-lab system and IBL methodology, and also to successfully implement ILSs in their school and with their students. Furthermore, the design and developed wide-ranging support methodology, that offered the necessary online and offline tools to teachers, as well as national coordinators, throughout the piloting sessions, has proven to be effective and with measurable results. The combination of engagement, training, support, recognition and community aspects and activities has been successful in engaging, motivating teachers and in many cases has led to a cascade effect where teachers were training their colleagues and peers in the use of the system.

This is one of the main reasons that the proposed sustainability strategy for the future development of the Go-Lab community and users is based on the idea of the expansion of the summer schools (as the "Go-Lab Academy"). The data has shown that the training provided on the summer schools has achieved the best results in terms of creation and implementation of ILSs.

Certainly, the factors contributing to the different usage of the Go-Lab system are influenced by a variety of different sources. The conclusions that can be drawn from the analysis presented above, and by matching the different support activities with the behaviour of the users are the following:

- Dissemination events were certainly an important trigger for users to visit the Go-Lab portal and become explorers;
- Engagement activities, such as the visionary and practice reflection workshops motivated the first level of engagement (users exploring the portal and registering in Graasp) and in many occasions triggered the next level of involvement (users using existing resources);
- Training events – especially the summer schools - were the most effective mean to promote users to the next level (Adopter/adapter of the resources);
- The continuous support provided by national coordinators and by the pedagogical and technical team were a key aspect for the emergence of the higher level of engagement: the creation and authoring of new ILSs.

Consequently, we believe that the Go-Lab support methodology has the potential to become a self-sustaining help desk where teachers can find help from the technical team, the lab owners, ILS designers and most important from their peers – even after the project's official conclusion.

During all phases of the large scale implementation more than 1.000 schools and almost 1.700 teachers reacted to the calls for participation in Go-Lab activities. Nearly 3.900 Graasp users have created new or used existing ILSs. For every teacher trained, almost 4 other trainers or teachers have registered in Graasp and explored the system, which demonstrates not only the technical pedigree of the system but also the potential of the applied support mechanism to engage and support such a large community.

6.9. Go-Lab moves to pre-service teacher training

UNIVERSIDADE D COIMBRA
FACULDADE DE PSICOLOGIA E DE CIÊNCIAS DA EDUCAÇÃO

Figure 108 Bachelor and Master Students from University of Coimbra participating in a Presentation of Go-Lab Ecosystem © NEXT-LAB

During the second phase of funding of the project (Next-Lab project) one of the objectives was to introduce Go-Lab in the pre-service teacher training institutes courses. With a mature and well tested system, it is important to start the introduction of the methodology and its associated infrastructure in the preparation of teachers, while still at University. The vision of this strategy is to prepare a cohort of new teachers, capable of influencing the in-service colleagues when entering the world of work.

In Portugal this initiative was implemented by the Department of Psychology of the University of Coimbra (Figure 108) with the support of Prof. Piedade Vaz Rebelo. Two groups of students were involved in the experiment: A group of 68 students from the Teacher Education Masters Course, from different subject areas (humanities, science and sports) and 50 from the Bachelor for Science Education. Go-Lab was integrated in the framework of the discipline of Contemporary Education Dynamics and Theory, more specifically in the chapter devoted to the introduction of Inquiry Based Learning. Go-Lab was implemented during five consecutive sessions. IBL was introduced during the first session, the subsequent sessions were dedicated to introduce them to the Go-Lab infrastructure, to reflect on their development and to the creation and presentation of their ILSs. Pre and post questionnaires were answered by the participants focusing on the conceptual and didactic-pedagogical knowledge about IBL and ICT, as well as their previous experiences, self-efficacy and teaching methodologies. The pre-questionnaires were answered at the beginning of the first session, prior to the formal introduction of IBL. Post-questionnaires were answered after the last session. The results evidenced lower level of pre-knowledge related to IBL which increased after the course, including their competence in knowledge creation while using the methodology and infrastructure ((Vaz-Rebelo et al., 2018). The main outcomes are presented below.

6.9.1. Masters Students Go-Lab training results

For this group the sessions had the following line-up (contribution of Prof. Piedade Vaz for the Next-Lab Teacher Training Institute Meeting in Brussels – November 2018) :

- **1st session**. Inquiry-based approach was presented. Mystery boxes activity.
- **2nd session**. Students registered in the Graasp platform and started to create their Inquiry Learning Space.
- **Developing the plan**. Meanwhile, students had to develop an IBL plan. During this phase, students communicated with the trainers by email or skype.
- **Reflection session**. There was a session dedicated to the analysis and reflection about the work in progress.
- **Presentation session**. Finally, each group presented their IBL plan and activity.

The distribution of the participants according to their main area of studies is presented in (Figure 109). All the sessions had the support of teachers from NUCLIO – Núcleo Interativo de Astronomia (national coordinator of the project in Portugal)

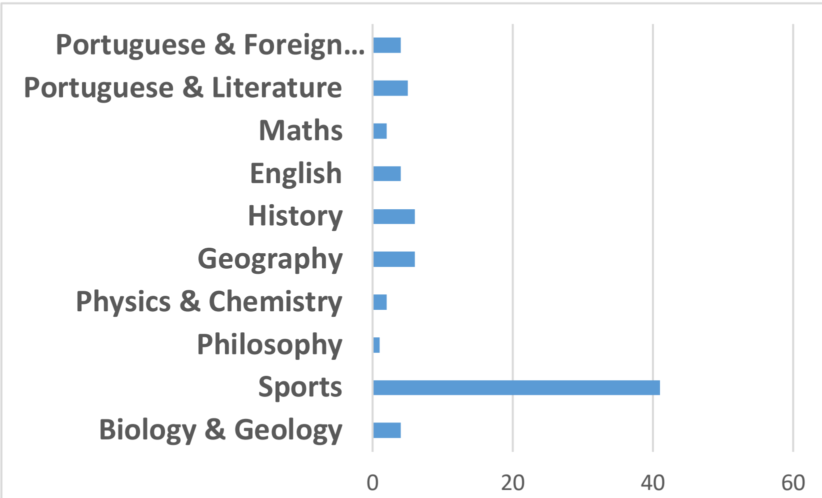


Figure 109 Area of Expertise of the Participants

This group had a large representation of students from the Physical Education Department followed by Geography, History and Portuguese with a smaller number of representatives from other subjects (Physics, Mathematics, Biology, English and Philosophy). The majority of students were from 20 to 28 years old. A total of 68 students replied to the pre-survey and 76 replied to the post-survey.

- In terms of attitudes of teachers related to their students: in general, participants had a good perception of their role agreeing with statements such as a teacher is a facilitator of learning, receives student's questions positively and encourages students to seek answers to their own questions. Nonetheless, the Go-Lab course still improved slightly their perception on the importance of this statements,
- In statements such as asks the students what they are interested in learning, take into consideration student's interests when building lessons we observed an improvement of the perception of the role of the teacher in a student-centred setting and more specifically while implementing IBL improved significantly,

- When asked about their agreement on the use of discrepant events to motivate students their statement clearly shifted in the post questionnaires answers towards a greater percentage of agreement,
- When asked about their agreement on not using a school handbook the difference was not significant and the vast majority did not agree with not having it.
- When presented the statement- a teacher focuses on student's understanding of concepts - more than 70% agreed with it in both pre and post questionnaires,
- Over 80% of the participants agreed that a teacher should involve their students in the study of different research questions throughout lessons and that students should develop their own hypothesis, develop their own experiments and analyse the data obtained and finally share their results with colleagues.
- Over 70% in the pre and over 80% in the post-questionnaire, students stated that their experiments help promote the development of their research skills.
- Over 70% of the participants stated that they had experience on the use of ICT in education,
- When asked about their knowledge on the use and implementation of IBL in their lessons we found that in the pre-questionnaire only ~17% manifested confidence in their knowledge. This number shifted to over 80% in the post-questionnaire.
- When asked about their knowledge on the use of various educational strategies and approaches, to promote active student involvement and cooperative learning, their agreement increased in the post-questionnaire.
- When asked about their experience in planning activities involving IBL and ICT their initial statement was of general disagreement with the statement (~70%) shifting to a more positive answer where over 50% agreed that they had experience.
- Related to their experience on the use of digital tools and repositories of educational materials, the post-questionnaire presented a nice evolution of the participants self-confidence where over 30% stated that they felt capable of teaching their colleagues how to use them.
- Related to the use of virtual simulations responders manifested a lack of experience on its use in the pre-questionnaire having their confidence on its use increasing in the post-questionnaire.
- Between 60 to 70% of responders, in the pre and post-questionnaire appreciate exploring new tools and technologies.

The complete results can be seen in Appendix VI.

The perception that teaching should focus on the understanding of concepts and relies on having a school handbook is expected for educators that are already in schools and often using as the most common approach the traditional teacher centred model. However, the group of master students, even though stating that they were initially not acquainted with IBL, had already a very good overview of the methodology giving important indications that they were already embedded it in their lessons, or at least having a good understanding of the importance of the different IBL components. The fact that there was a shift from 17% to over 80% on agreeing with the statement that they had enough knowledge about IBL to use it in classroom shows that they were already using the methodology or at least parts of it. The training boosted their confidence on knowing how to assess their students when involving them in IBL experiences. The experience also provided them with more confidence towards their understanding of and use of various educational strategies. Their confidence on their own skills to use IBL and ICT after the course was also evident when comparing the pre and post-questionnaires. A large fraction of the participants enjoyed using technology and after the course felt more confident and empowered with the integration of virtual simulations on their lesson.

An important part of the training was related to the use of IBL. In order to evaluate the efficacy of the training we presented a series of different classroom practices where we asked participants to identify those that were inquiry and those that were not. Over 45% or responders, even after the training, failed to recognize that following a protocol to develop an activity is not inquiry, although this specific topic was debated during the course. On other aspects, such as the capability of explaining a phenomenon while using a chart, the characterization of a recurring phenomenon, the discussion of a topic, collection of evidence and proposing strategies the answers shifted towards a good perception of IBL to over 80% of the participants.

While building their own ILSs, students generally chose the basic scenario where the phases of inquiry are divided in: Orientation, Conceptualization, Investigation, Conclusion and Discussion. The integration of the different lesson components in the different phases of the ILS was challenging to most of the participants. In general, the more difficult ones were the conceptualization and the investigation phases. Participants often asked the tutors what to integrate in each part. Several discussions were conducted in order to clarify that inquiry-based learning is not a one direction journey. An online laboratory (or physical experiment) could be integrated at the very beginning of an inquiry process as a step in the orientation phase. It can be used to clarify concepts or remember previous knowledge. In terms of the usage of the infrastructure participants didn't find it particularly challenging and quickly grasped the basic functionalities of the system. Most responders found the introduction of text, links videos and apps relatively easy. The challenge was the creation of the general scenario, more due to the authoring process itself than the presented technology.

6.9.2. Bachelor Students Go-Lab training results

For this group the sessions were the following (contribution of Prof. Piedade Vaz for the Next-Lab Teacher Training Institute Meeting in Brussels – November 2018) :

- **1st session**. Inquiry-based approach was presented. Mystery boxes activity.
- **2nd session**. Planning an Inquiry Scenario
- **3rd session** Presenting and discussing the IBL scenario in the class
- **Presentation session**. Finally, each group presented their IBL plan and activity.

All the sessions had the support of NUCLIO.

The majority of the participants were female (over 90%). Their age ranged between 20 to 25 years old. These students are taking the Bachelor for Science Education. A total of 53 students replied to the pre-survey and 62 to the post-survey. Some highlight conclusions are presented below:

- Most participants had no prior experience on the use of IBL,
- The post-questionnaire responders showed appreciation for the methodology finding it a good way to promote interest and motivation for learning,
- The vast majority of the participants stated having a good expertise on the use of ICT and its integration in their own learning journey,

- When asked about their knowledge on ICT for planning and implementing activities most responders (over 60%) manifested lack of such skill. The number shifted and over 60% responded positively in the post-questionnaire,
- Their confidence on how to evaluation educational activities while using IBL methodology also have grown after the course,
- Over 40% had knowledge of various educational strategies but the number still evolved to nearly 70% after the training,
- The same can be said related to the selection of effective educational approaches to promote student active involvement and cooperative learning,
- Prior to the course responders stated that they didn't have experience on planning IBL activities and ICT. That changed to over 60% declaring having such experience,
- The ICT experience of responders was fairly good but their knowledge on the existence and use of virtual simulations was not good prior to the training.
- They also manifested a good attitude towards the exploration of new tools and technologies.
- Their understanding of IBL clearly improved when comparing the pre and post-questionnaires.
- Similar levels of difficulty were manifested related to the construction of their ILSs. For the orientation phase no major problems appeared. For the conceptualization and investigation phases we found more responders stating it was difficult.
- The use of the platform was not a problem for the majority.

The answers presented above clearly show that the course acted as a motivator towards the use of IBL methodology and boosted the participant's confidence on its use. Their experience on the use of IBL is expected to be low since they are beginning their bachelor and probably had very low exposure towards IBL while in school.

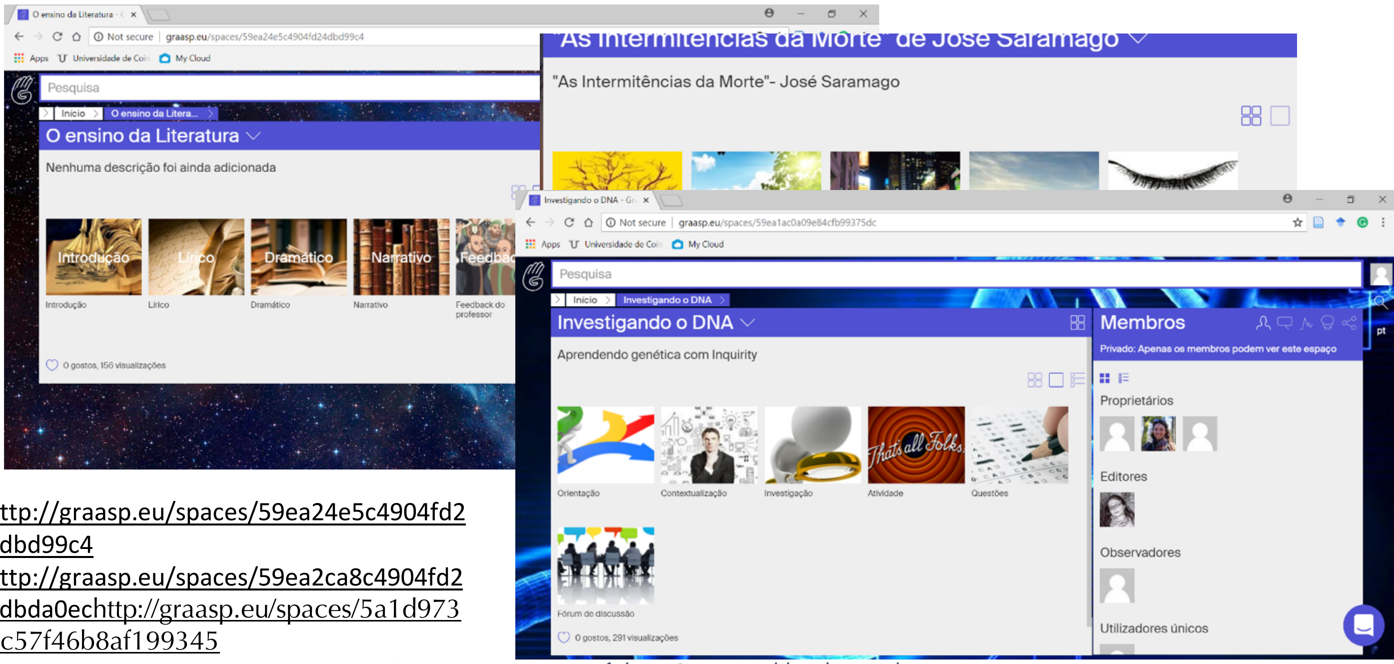
This group revealed a higher level of confidence on the use of ICT but more obstacles to create their IBL examples. They lack still the experience and maturity to be able to properly prepare their scenarios. Nonetheless, the scenarios presented were very good and very adapted to the potential professions this group will have available for their future careers.

The audience of the two groups was not comparable since they came from different types of groups. The bachelor students were from science education while the others were already doing their masters, and often with already some expertise in teaching. None of them had a good representation from STEM fields. Both groups of participants revealed a good knowledge on ICT and revealed very little or no difficult in understanding how the Go-Lab ecosystem works. A detailed study of the student's answers before and after the experience shows a large enrichment of terms related to student centred and IBL model. In general all the remarks were positive with a few exceptions regarding the risk of students finding wrong information and the need to pay closer attention to students with special needs.

The statistics studies applied to these questionnaires didn't reveal any possibility for a more in depth study of the results. However, it was enough to help understand the necessary effort in order to properly integrate this training in the respective courses and to reflect on the impact of this methodology on their learning and understanding of IBL. The course enriched this specific component and the result of their work revealed to be very encouraging for the continuation of this effort.

This empiric experience also revealed that for these students ICT is not a challenge but the integration and construction of their lessons was very challenging. When dealing with in-service teachers the reality is the opposite, the first major obstacle tends to be the use of ICT and its integration in daily practices. Again, the comparison needs to be made with caution, as already mentioned above the students reached by this study were not from STEM areas whereas the in-service teachers involved in the previously presented studies were.

As a result of this effort 40 ILSs have been created: 25 from the teacher education masters course students and 15 from the bachelor's in education sciences students. A few examples can be seen in (Figure 110).



http://graasp.eu/spaces/59ea24e5c4904fd24dbd99c4
http://graasp.eu/spaces/59ea2ca8c4904fd24dbda0echttp://graasp.eu/spaces/5a1d9732c57f46b8af199345

Figure 110 Images of the ILSs created by the students

In general most of the scenarios were very creative and the attempt to properly build an ILS was evident. Most also presented clear team work. The Orientation phase in most cases needed some improvement in order to be appealing for the students, to sparkle their curiosity. Most failed in giving the flor to the students to build their own hypothesis, however, an effort was in place to give some freedom for students to manipulate at least one variable. Many were written as a presentation to the course and not something that could be used by students. All scenarios used several of the ICT possibilities of Graasp and were enriched with videos, links and apps. All presented a great deal of creativity and several unique ideas for interdisciplinary learning emerged from there.

6.10. GO-GA – Go-Lab goes Africa

Figure 111 Visual Identity of GO-GA Project © GOGA

The success of the Go-Lab project enabled the consortium to start a new phase of development, this time reaching out to developing nations in sub-Saharan Africa. The project is called GO-GA – Go-lab Goes Africa (Figure 111) and it is funded by the European Union through the framework H2020 research and innovation programme. Three countries are involved as partners in the first stage of the project: Benin, Nigeria and Kenya. Other countries will participate in a later stage.

In GO-GA, the lessons learnt in the framework of Go-Lab are the starting point for this challenging and important mission. One of the important tasks is the development of a solid program to train the master teachers, a fine selection of teachers that will have as a mission to train other teachers.

The train the trainers Bootcamps took place during the months of September to November 2018 (Figure 112 & Figure 113). During these events we had the opportunity to pilot test the model proposed to introduce Go-Lab ecosystem to beginners. The "Introduction to Go-Lab" document with the basic structure of the "Train the Peers Strategy", developed in the framework of Go-Lab is presented in Appendix VII

All the learning of the previous projects was summarized to ensure a successful outcome. To the list already presented in Chapter 1 we have added:

- All sessions now start with an ice-breaking where participants get to know each other and their trainers,
- Some initial design thinking is in place in order to ensure trainers understand the level of awareness participants have related to the technical solutions being presented, the knowledge content being shared and the pedagogical model that will be used during the training,
- Sessions begin with fun warm-ups and whenever is necessary energizers are introduced.

All these ingredients aim to ensure participants feel comfortable with each other, with their trainers and feel engaged throughout the training event.

Figure 112 Master teachers trained in Lago's Bootcamp (October/2018) © GOGA

Figure 113 Master teachers and trainers in Nairobi's Bootcamp (November/2018) © GOGA

All the knowledge accumulated in the previous steps was put in place in GO-GA. The group of teachers involved in the first pilot phase was carefully chosen according to their location and skills. This cohort of teachers have in their hands a very important mission: "empowering their colleagues to embrace the necessary change in their education systems". The training events aggregated important components, having not only in mind the use of Go-Lab infrastructure but also the whole methodological and pedagogical model behind it. GO-GA is bringing not only IBL integrated with ICT, it is bringing a new way for teaching and learning. The "Train the Trainers Bootcamps" had the following components;

- Ice-breakers and team building to build trust and create a positive environment,
- Meet and greet opportunities to provide insight on the participants background and prior knowledge, a very important step to build a strong relationship with the participants,
- A brief Introduction to the project in order to build confidence in the team supporting their training,

- Introduction to inquiry based learning and its integration in the Go-Lab ecosystem
- Introduction to the Go-Lab ecosystem in a step by step approach, always starting from the participants comfort zone, ensuring equity was present all the time.
- Co-creation and interdisciplinary based learning approaches,
- Train the peers strategies
- 21st century skills and how to assess them
- Brainstorming on opportunities and challenges

From these components the one to which we devoted more time was the discussion related to opportunities and challenges foreseen by the Master Teachers. These were key points for actions to be taken in order to support their field work while involving their students and engaging their peers (Figure 114).

Figure 114 Teachers in Nigeria during the brainstorm session © GOGA

Design thinking was used throughout the training in order to accommodate the specific needs of the participants. During the whole process care was taken to ensure every participant felt part of the project, to provide a sense of ownership and to jointly create solutions and future opportunities. Participants had already participated in training events and the boot camps were an opportunity to go more in depth in certain aspects such as how to build a real IBL space, what apps should be used, how to empower their colleagues, etc. The training sessions were coordinated by NUCLIO with support from EPFL, University of Twente and the local partners (Etrilabs – Benin, CcHub – Nigeria, eLimu – Kenya). The training program was co-designed by all partners and its delivery integrated the model we were presenting to them. In other words, we introduced them to IBL while using IBL, the different topics were presented in an interdisciplinary format and team building activities and energizers were in place all the time. Several hands-on activities were introduced to them and care was taken to ensure they would be able to later replicate the example with their peers, for example:

- Introduction to IBL with mystery boxes,
- Hands-on interdisciplinary learning,
- Experiment an ILS as students.

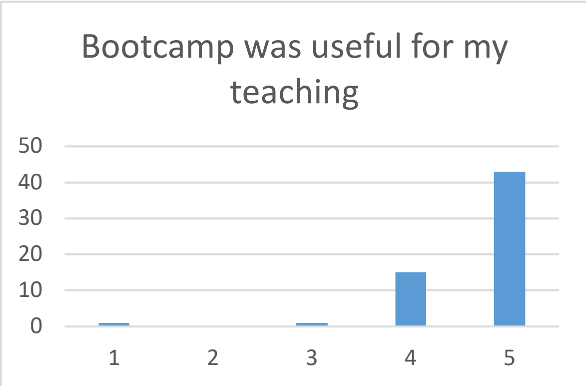
The mystery boxes activity was very appreciated by the participants and proved to be a very good way to introduce inquiry-based learning to teachers (Figure 115).

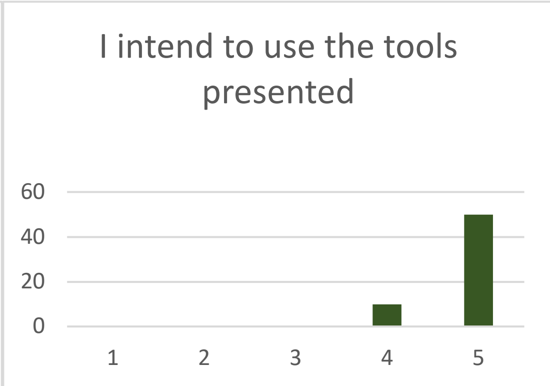
Figure 115 Teachers in Nigeria participating in the Mystery Boxes activity © GOGA

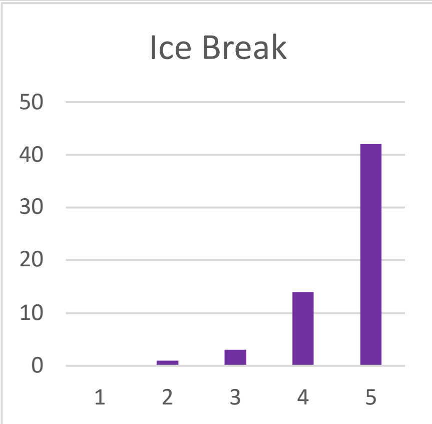
For the warm-ups and energizers, we used astronomy exercises such as finding the scales in the solar system, astronomy versus astrology, moon phases, etc (Figure 116)

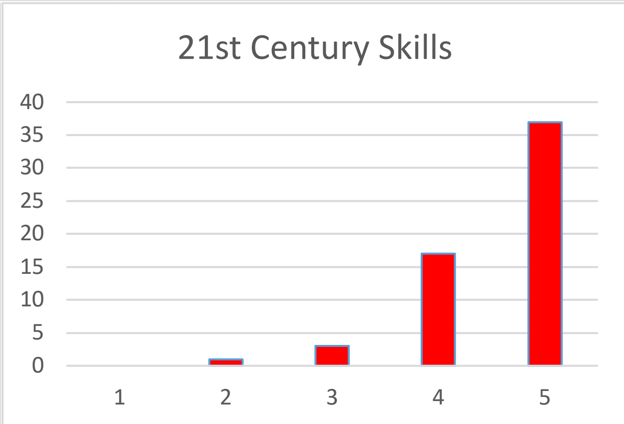
Figure 116 Teachers in Kenya learning about the distance to the Moon © GOGA

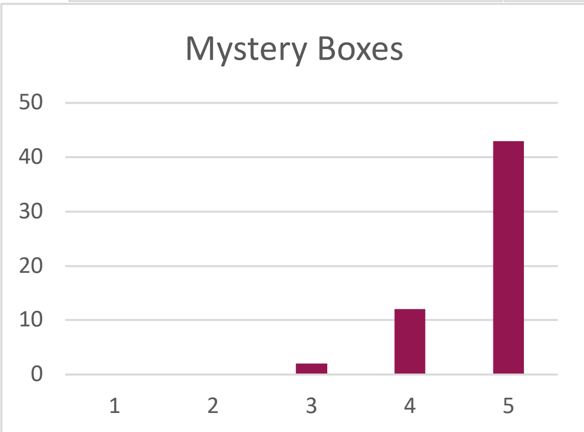
After the training session, participants were requested to answer an evaluation form (Figure 117). The results were very encouraging as can be seen from the examples below. They had to evaluate each session from 1 to 5 (1 -Completely disagree or give the lowest value
5 - Completely agree or assign the highest value):

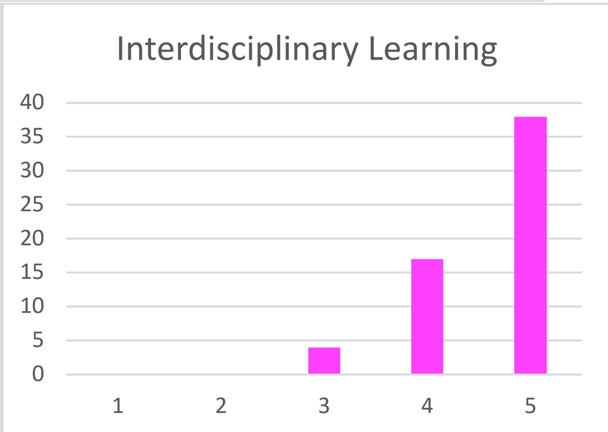












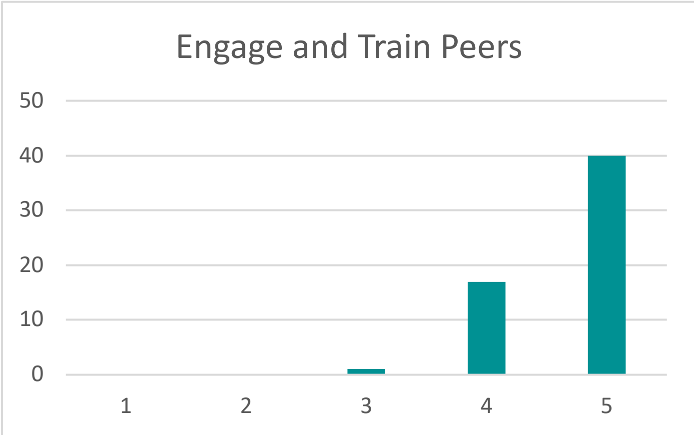


Figure 117 Replies to the Master Teachers' Training Evaluation Form

In terms of obstacles for the project implementation, replies were no different than what we found in Europe as can be seen in 6.4 (Figure 118 & Figure 119)

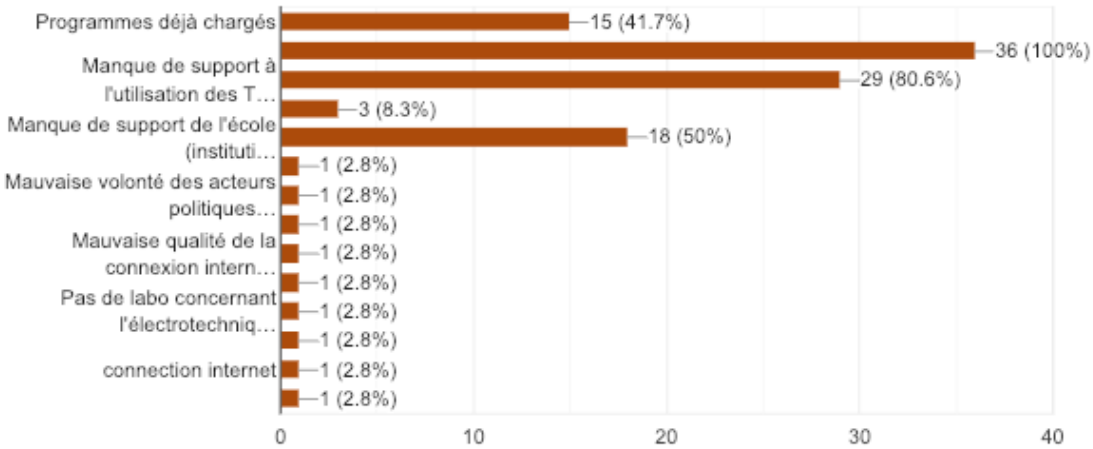


Figure 118 Results from the training in Benin

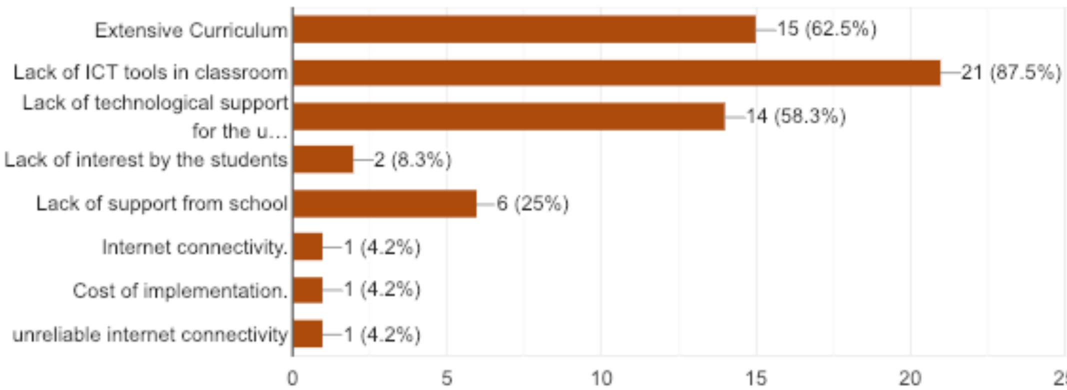


Figure 119 Results from the training in Kenya

The biggest difference found was in their attitude towards these difficulties. Participants were very committed to find solutions to all the problems presented and discussed during the boot camps. Stakeholders involved in the process offered support, teachers volunteered to bring their own mobile internet equipment, even for cases were no electricity is available at the school solutions were proposed. Having a national representative, the motivation of being a master teacher, in charge of engaging others, the presence of a strong support from local stakeholders and the several training opportunities seemed to be the perfect recipe for them. In fact it is well know that localization of solutions, flexibility and perseverance, and decentralization are part of the solutions to bridge the digital and education divide (Gaible & Burns, 2014). Having a local partner such as the ones representing each nation in GO-GA and/or teacher training institutions supporting the implementation of the program is very important as they can ensure a continuous follow-up support, computers facilities, etc.

The future will tell us if this assumption correct or not. When asked to describe in three words the training to which they participated this was the result (Figure 120):

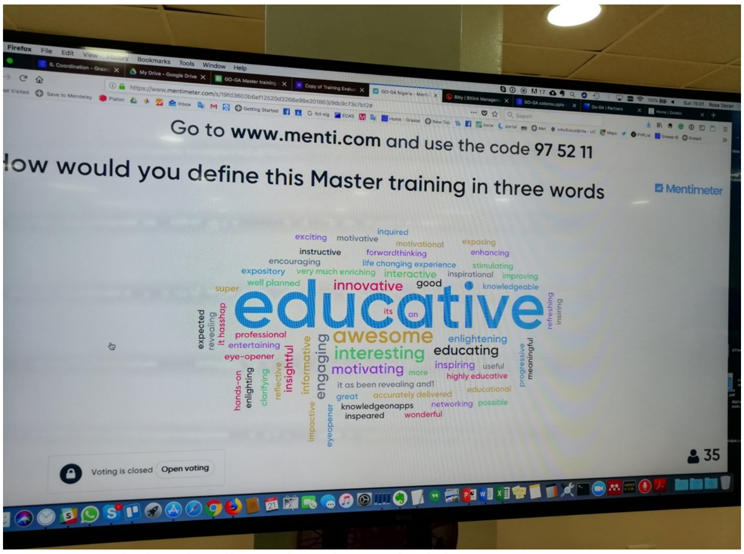


Figure 120 Word cloud collected at the end of the Bootcamp in Nigeria © GOGA

It is still early to make any measure on the impact of the training. The official phase to onboard the new teachers will start only in 2019. After the second year of the project we will have more information about how many of them have created and used their ILSs with their students and how many new teachers they successfully brought to the system. But some considerations can already be drawn, the first and most evident is the need to inspire more girls to take an interest in science subjects. As can be seen in Figure 121, the percentage of female teachers in the master teachers group selected in the 3 countries, in science domains, is less than 30% (Gillet et al., 2019). According to the participants this is a reality in schools where girls tend to think that science is not for them.

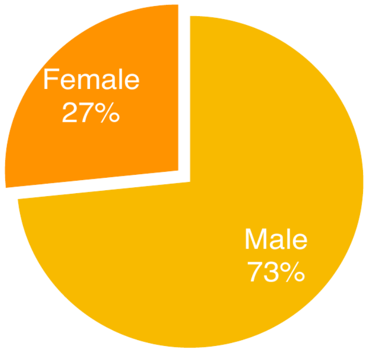


Figure 121 Overall Master Teachers gender spread in the three pilot countries. The graph indicates a strong gender imbalance, with male teachers prevailing in a ratio of approximately 7 to 3.

Another interesting outcome relates to the number of ILSs created per country. In average 1.4 ILS were created per Master Teachers and 2 per school. But Kenya is the country presenting by far the largest number of ILSs created which might be the result of having at least two Master Teachers in each participating school acting as a strong mutual support (Gillet et al., 2019) (Figure 122).

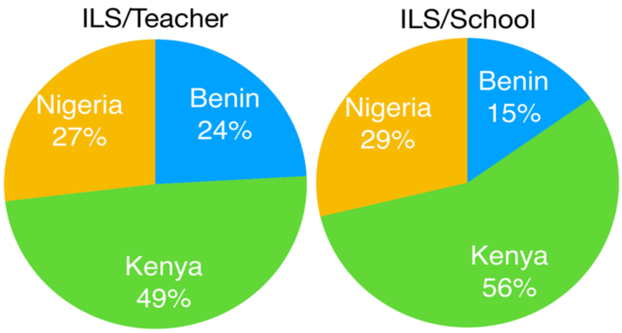


Figure 122 Percentage of ILSs created per Master Teacher (left) and per participating school (right) for the three pilot countries. Clearly, Kenya leads the score in both regards

The experience of training these teachers was absolutely overwhelming. Their humble and brave attitude, in all the countries, when facing the difficult task of learning and devising a mean to implement a project that is in the cutting edge in terms of science education, is a lesson to all of us. Nothing is a challenge big enough for this cohort of champion teachers. When you ask a teacher what are the impediments and you listen to a list of things that you already know plus a few barriers that one would not really think of encountering, such as lack of electricity, having 100 students in the classroom, having 2 to 3 jobs in order to have the necessary financial income, you don't expect their attitude to be positive. Instead the solutions were more than the difficulties presented. When you have a group of female teachers saying goodbye to you with the words "thank you for coming into my life", stating how GO-GA is important to the future of Nigeria and how it goes beyond science literacy in Kenya or an almost retired teacher saying, "I am so glad this happened in my lifetime", you know no effort is too much!!! (Figure 123, Figure 124, Figure 125 and Figure 126).

Figure 123 A teacher from Nigeria explaining how Go-Lab can be important to the future of Nigeria © GOGA

Figure 124 All the female teachers attending the Master Training in Benin © GOGA

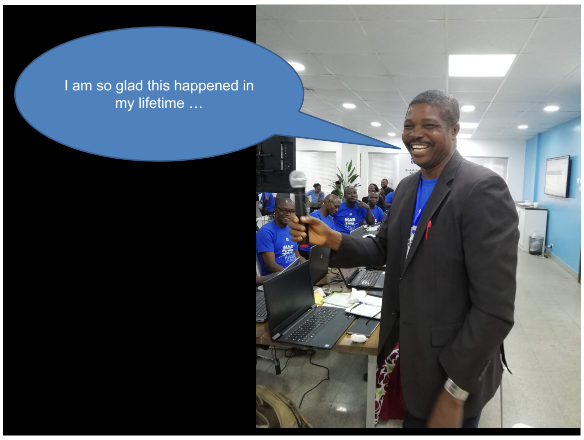


Figure 125 A teacher in retirement age stating how important the project is to him © GOGA

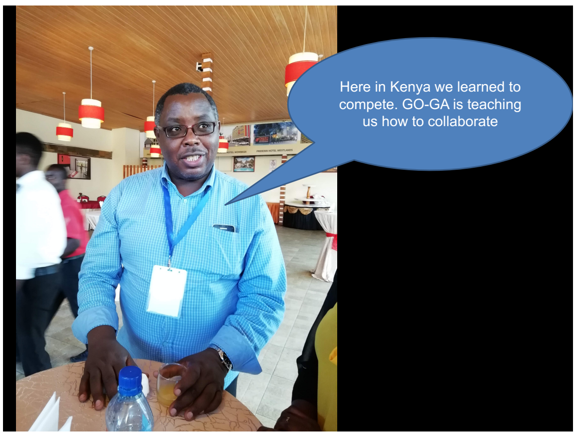


Figure 126 One of the trainers in Kenya explaining how GO-GA goes beyond science literacy © GOGA

7. 21st century skills - Learning methodologies promoting education and skills for future challenges

In the previous chapter focus was put on the role of science outreach and authentic scientific exploration in classroom. Several examples were presented were the methodology to empower teachers was perfected, tested and validated in different settings from the developed to developing world. All the actions focussed on empowering educators to shift their way of teaching to a more student-centred learning approach. Across the globe discussions are taking place on what is the right measure for the new generations' preparation for the 21st century. Should educators focus more on content knowledge or acquisition of key skills? Can both be done simultaneously? According to (Hilton, 2010), science is the perfect context to merge the two goals, learning content while exercising important skills such as communication, problem solving, developing and presenting an argument, etc. In the same document we see a very interesting list of 21st century skills, that students will certainly need when they reach the world of work:

- Adaptability and flexibility
- Communication and social skills
- Non-routine problem solving
- Self-management and development
- Computational thinking
- Drive to achieve
- Persistence and resilience

These and other competencies are key for the world of work where employees have to be able to collaborate with others, being able to argue and present information, suggest improvements, solve novel problems, find creative solutions and ways to improve performance and quality, etc.

In fact, in the same document, Hilton presented a list of statements related to how industry and other business corporations are looking for such skills when hiring new members for their teams. NASA science education effort is mentioned as a program that supports the development of such skills. The document clearly outlines inquiry, and science and technology as most relevant for the development of 21st century skills. The first one to include communication skills and to plan and select appropriate evidence. The second one includes technological design, which involves computational thinking and problem solving.

In (Hilton, 2010) we also find a large number of references to the school science content that are now part of the Next Generation Standards and how they relate the necessary flexibility between subjects and grades and their importance for the construction of a solid base of competencies.

In order to achieve a graceful merge between IBL, interdisciplinary learning and 21st century skills a lot needs to be done. Learning environments need to be prepared to accommodate this reality. Classrooms have to inspire collaboration and create a relaxing environment were learning happens naturally. Content knowledge and skills development need to be adapted to the students' personal preferences and capabilities. Science should be facilitated by means of inquiry or project-based learning. Assessment needs to be in line with the model adopted and professional development of educators needs to accompany the whole process, through regular, updated and effective training opportunities, also adjusted to the needs of the teachers.

A more complete and updated list of 21st century skills can be found in (OECD, 2018d) where a large discussion is taking place to find what are the needs for each country.

After the overall experience presented in previous chapter and after understanding what was necessary in order to ensure new models for learning would reach students and how to effectively prepare educators to do this, we felt the need to develop a project more focused on inquiry based learning and interdisciplinary integration.

7.1. PLATON - Inquiry and Interdisciplinary Learning for Dummies

Inquiry based learning as presented by (Rocard, 2007) has proved its efficacy for both primary and secondary levels. It is effective for students with different characteristics and learning preferences and adaptable to individual needs. The inclusion of inquiry based learning in classrooms and properly preparing educators to facilitate learning using this methodology is presented in (Osborne & Dillon, 2008). Both documents were used as reference for a series of European Commission funding calls for Science and Society. According to (Freeman et al., 2014) active learning improves the performance of students and is a very effective way to promote science education.

But the introduction of inquiry will not suffice per se, it is necessary to build a whole culture around inquiry (Alberta Learning, 2004) as it requires a school vision around its implementation in classroom, collaboration and team work and it requires a systematic approach towards its use. The benefits are many: it allows for an easy and seamless contextualization of the teaching content, sparks student's curiosity, changes the attitude of the teacher to a proactive facilitator of learning, and it presents students the opportunity to take ownership and responsibility for their learning, to name a few.

The main objectives of the application of IBL are concisely described in (Harlen, 2013). Good scientific literacy requires that students:

- Understand the fundamental ideas of science,
- Understand the nature of science and the scientific method,
- Acquire skills for the acquisition and use of scientific evidence
- Develop a scientific attitude related to science,
- Acquire the necessary skills to continue the path of lifelong learning,
- Develop oral and written communication skills,
- Understand mathematical language,
- Realize the importance of science's contribution to society.

Throughout this document slightly different formats of the inquiry cycle were presented in the different projects. For Discover the Cosmos the inquiry cycle had the following format (Sotiriou, 2011):

- Phase 1- Question Eliciting Activities: Exhibit Curiosity, Define questions from current knowledge,
- Phase 2 – Active Investigation: Propose preliminary explanations or hypothesis, plan and conduct simple investigation,

- Phase 3 – Creation: Gather evidence from observation
- Phase 4 – Discussion: Explanation based on evidence, consider other explanations
- Phase 5 – Reflection: Communicate explanation

In Inspiring science education the cycle was described as (Rutten et al., 2015):

- Orienting and asking questions – the whole process can start with a question, a dilemma, a problem. The trigger can be a class discussion, a video, a simulation, etc. Anything that will spark the interest of the student.
- Hypothesis generation and design – After refreshing their prior knowledge the students are invited to structure the problem they are going to work with. A proper support is necessary to enable a proper construction of hypothesis, a very difficult step for students.
- Planning and investigation – students need to define the tools they are planning to use, determine a timeline, etc.
- Analysis and Interpretation – In this phase students will analyse the data retrieved during their investigation.
- Conclusion and Evaluation – Students will collaborate with their colleagues in order to reach a conclusion.

And finally in Go-Lab the Inquiry Learning framework was defined as 5 phases interconnected and to be followed in a non-linear way, as can be seen in Figure 127, (Pedaste et al., 2015):

- Orientation – spark the curiosity and interest on the topic
- Conceptualization – Retrieve prior knowledge and general hypothesis
- Investigation – integrates exploration, experimentation and data interpretation
- Conclusion
- Discussion

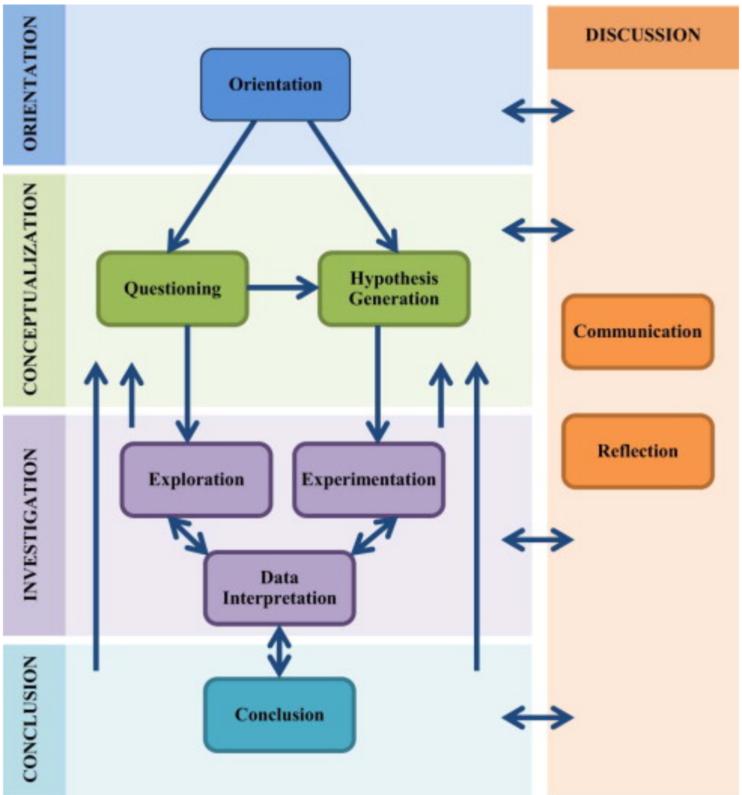


Figure 127 Go-Lab inquiry learning framework © GO-LAB

Introducing these models to teachers and providing a deeper understanding of the logic behind this methodology is rather easy to do. But when we ask them to start migrating their lessons to the inquiry-based model, then failure to accomplish this becomes a general trend. Teachers accustomed to the expositive model, even the less traditional ones, seem to have a huge difficulty in structuring inquiry activities. They have to ensure that the scenarios they are about to build integrate the necessary components of the curriculum, while at the same time giving the floor to students, ensuring prior knowledge is presented and also enabling them to make their own route towards finding the best fitted results. Furthermore, teachers should promote collaboration among students and between the different teams. During the process students have to propose their own hypothesis, discover a mean to retrieve the necessary information to test their hypothesis, design their own experiments, analyse their results and make unbiased conclusions. Teachers should provide students with all possible opportunities to fulfil their mission, assess each student individually, and be an observer during most of the process. In the most authentic IBL experience, students select the topics they are interested in, propose the means for their own experiment, autonomously build their knowledge on the specific topic they are about to research, starting from their previous knowledge and possible misconceptions. All of this can present a great leap from the teachers' comfort zones and insecurity takes place. Furthermore, students often feel lost when they begin an Inquiry approach as they are mainly used to following guidelines instead of thinking on their own. However, more structures of Inquiry scenarios can be integrated in order to facilitate the transition from traditional learning to a full Inquiry experience.

The inquiry process can start from a very structured model towards a model where tutors will only provide some guidance and finally a more open approach where the teachers have little or no control over the whole process. For students the process should be the same, starting from the most structured proposal slowly providing more freedom and responsibility towards the whole experience. In order to achieve such progress and transition, teachers should feel comfortable, secure and experienced. This can be achieved through specific teacher training actions which provide teachers with skills and know-how, but also with motivation and security. One example of such effective teacher training framework is PLATON - Promoting Innovative Learning Approach for the Teaching of Natural Sciences (2016-1-PT01-KA201- 022881) - a project co-funded by the Erasmus + Agency of the European Commission in the framework the KA2 – Strategic Partnerships.

PLATON focused in creating an effective teacher training framework which promoted student centred approaches, the creation of a collaborative holistic and interdisciplinary approaches in schools, and the integration of ICT in class. These were integrated in an innovative methodology named WILL (Working with Inquiry and Interdisciplinary based learning), which introduced teachers to Inquiry and Interdisciplinarity in a progressive step-by-step transition (Doran, P. et al., 2018). PLATON differed from previous methodologies by motivating teachers to shift from traditional to an Inquiry and Interdisciplinary student-centred approach in a series of small steps instead of pushing them to make the transition in one often "scary" giant leap. Such methodology is hence explained in more detail:

7.1.1. From the Big Ideas of Science to Interdisciplinary Learning

In general teachers are accustomed to work isolated or in the best case scenario collaborating with their colleagues from the same subject domain. Interdisciplinarity is not an easy concept to apply, in general, as an approach for learning. We realized that surprisingly enough, most teachers were not aware of the program being taught by their colleagues in other disciplines and very rarely or even never collaborated by connecting topics. As change is often a difficult thing to embrace, teachers usually present resistance when innovative methodologies are proposed. As such, to overcome the existing barrier towards the concept of Interdisciplinary learning, several strategies were created.

- Tangram Challenge
  Teachers are invited to create a series of tangrams individually. Each tangram individually completed intendeds to exemplify one different subject domain (Physics, maths, etc.). After completing this first step, teachers are invited to take a closer look to the games and try to find out the hidden message. After they understand that there is a hidden pattern in the background image of the pieces, teachers are invited to recreate the tangram. When finished, teachers realize that they have built a much completer and more meaningful picture, which represents the big picture achieved when using Interdisciplinary learning approach instead of separating knowledge into isolated and unrelated subject domains (Figure 128).

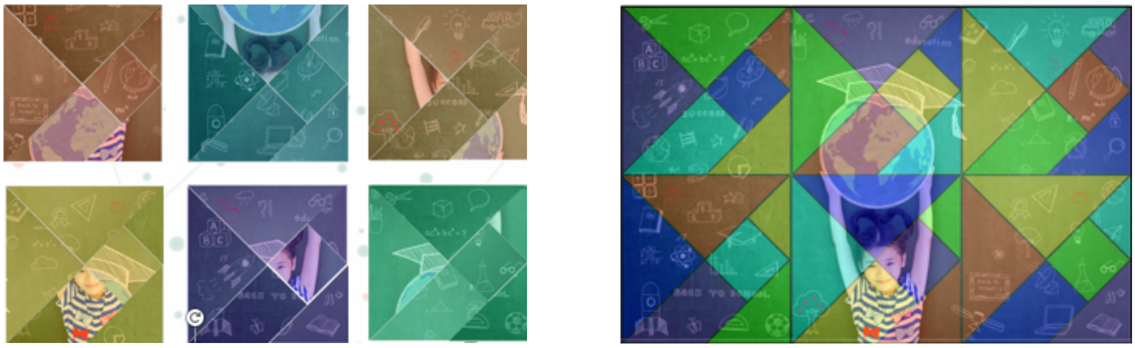


Figure 128 The tangram challenge © PLATON

The tangram challenge represents the first approach towards overcoming the teachers' psychological objection towards collaboration with their colleagues. When finishing the puzzle, teachers usually show surprise and acknowledge the benefit of an interdisciplinary approach.
This challenge is a good way to represent the importance of interdisciplinary learning, however, it doesn't provide teachers with the skills to know how to get started. As such, a second approach was created.

- Story Boarding

This activity begins by asking teachers to write down in post-it's all the concepts they have to teach during the following period. Then, a series of random images is presented, and teachers are challenged to create a story that integrates all the pictures. This can be a suspense, romance, etc. but, all images have to be used. After the story is prepared teachers have to associate all the post-its to parts of the story they created. This activity was carried out over 10 times and in all of them, all the post-it have been somehow associated to the story. Once they finish putting their post-its, teachers realize how their topics can all be taught using one same story (big picture) and that different subject domains present topics related to each other (Figure 129).

Figure 129 Teachers in Lagos (Nigeria) creating their stories © GOGA

Both activities presented an effective and motivating introduction to interdisciplinarity, preparing the teachers to explore the Big Ideas of Science.

- Big Ideas of Science

In PLATON a specific set of ideas was used developed in the framework of the project Go-Lab (Tsourlidaki, Sotiriou, & Doran, 2016). Three separate sets of Big Ideas were made available for different age groups[40]. Then a 3D Interdisciplinary Map of Science Ideas was created as a mean to interconnect different concepts, through the Big Ideas of Science, allowing teachers to build the necessary interconnections between the topics they teach. The map was presented in 3 levels (Figure 130).

Level 1 – Big Ideas of Science - 8 ideas
Level 2 – Intermediate Ideas of Science – 21 ideas
Level 3 – Small Ideas of Science – 86 elements (curricula topics)

The 86 small ideas were created from the curricula of all countries participating in the project and acted as a starting point for the creation of interdisciplinary activities. The scheme created allowed for the integration of concepts from different subject domains and different grade levels. One example of a small idea of science can be seen in (Figure 131).

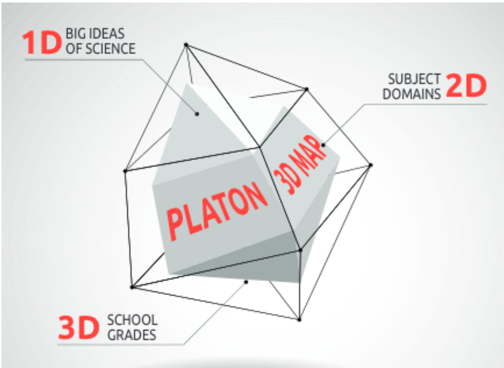


Figure 130 PLATON 3D Map of Science Ideas © PLATON

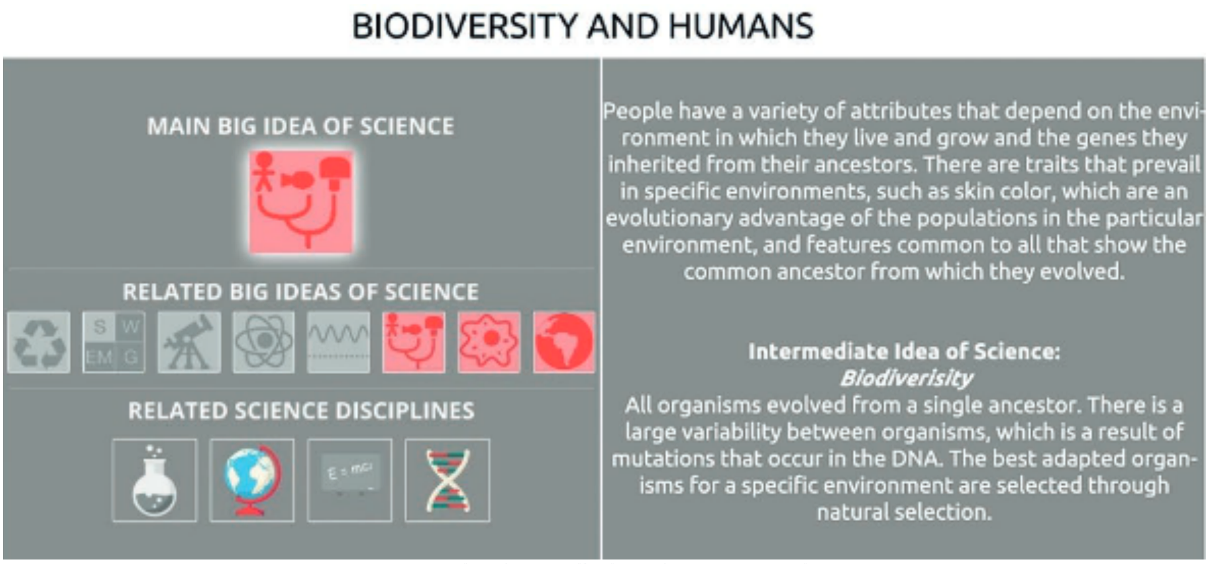


Figure 131 Example of a Small Idea of Science Card © PLATON

Over 200 teachers worldwide received training on the use of this model. During the training they had the opportunity to use these materials and in collaboration with other

[40] http://platon.ea.gr/content/big-ideas-science-0

participants of the training events or colleagues from their schools create interdisciplinary lessons. Some schools accepted the challenge to discuss the big ideas with their students and in some cases even created their own personal set of big ideas of science (Figure 132).

Figure 132 Students in a Greek school working with the Big Ideas of Science © PLATON

7.1.2. PLATON – Inquiry under the Microscope

The other important pillar of the project was the introduction of inquiry in a step by step approach. The idea was to transform the usually presented IBL methodology to a more user-friendly language that could act as steps of an inquiry process that teachers could take one by one while slowly changing their teaching practice. As such, inquiry was divided into 9 different components that could be separately integrated in any learning activity. This was called the "Inquiry Under the Microscope toolkit" and it is composed by the following components:

1. **Setting the scene** –Teachers introduce the topic sparking the curiosity of the students, create expectations about what is going to be the inquiry journey, explain why that piece of knowledge is interesting and/or useful,
2. **Refreshing prior knowledge** –Teachers ensure every student is brought back to a comfort zone by activating previous knowledge related to the topic that will be studied,
3. **Wondering about how something works** –Teachers give the floor to the students and ask them what they think about the subject presented to them, allowing them to state their ideas and create hypothesis,
4. **Thinking about how to test hypotheses** –Teachers guide the students, giving them the chance to think about how they can test their ideas, helping them to design experiments and other activities to discover if their hypothesis are correct or not,
5. **Doing research and collecting data** – Teachers allow students to text multiple variables and experiment in order to decide whether a hypothesis is correct or not,

6. **Interpreting data and drawing conclusions** – Teachers provide students with time and guidance to organize and analyse data in order to draw conclusions.
7. **Comparing conclusions to hypothesis and existing theory** – Teachers promote the comparison between students' initial ideas with new knowledge and try to understand if the data they have is enough to solve the question at hand. Results are also compared to existing theories and students are invited to find existing theories on the topic and alternative solutions that could also be correct.
8. **Reviewing and reflecting on what has been done** – Teachers promote the reflection about the students' journey, what they learned and possible future outcomes,
9. **Discussing and connecting with everyday life** – Teachers create a discussion among the class about what was learned and how it relates to other topics and everyday life.

Having access to these components, teachers choose one at a time to implement in their practice (not necessarily in the number order), step by step until they feel comfortable with the process. When beginning, teachers should choose a more structured type of inquiry and only after they and their students feel comfortable they should move to a more guided approach and only when proficiency is around move towards a more open inquiry.

Teachers participating in the PLATON training events were invited to try each component using the inquiry under the microscope supporting cards, the PLATON flip cards on inquiry. Each card started with the description of the traditional practice that corresponded to the Inquiry practice, next an explanation on why there is a need for change and some examples of an inquiry practice to fulfil this step, following an example and some inquiry tips.

Furthermore, in order to illustrate how any given topic can be taught following an inquiry approach, a series of short-term and long-term activities was created by the partners, following the suggested structure to be used as examples by the teachers. Teachers were invited to use them in their daily practices and re-use/re-purpose them as they saw fit. They also served as starting point for the construction of their own activities.

7.1.3. Teachers and students at the 21st century – Inquiry and interdisciplinary learning

Knowing the importance of the community building efforts and the competence profile of teachers, in Portugal, we conducted a certified and accredited teacher training event (Figure 133). The training was in the form of a workshop (50 hours course), divided in face-to-face training and implementation in the classroom. The course introduced the two pillars abovementioned through interactive and practical activities. Teachers were invited to plan an interdisciplinary lesson using the 3D Map of Science Ideas and to use the Inquiry components one by one according to their level of confidence and preparation. Over 120 teachers participated in the training events conducted in several parts of the country. Furthermore, teachers from the countries participated in short training sessions focusing on the same, although not so in depth and a 10h online course was promoted to train teachers from non-partner countries. Their testimonies can be found in the project's social media[41]and in the final deliverable of the project, the roadmap to innovation (Doran, P. et al., 2018).

[41] https://www.facebook.com/platon.eu/

Figure 133 PLATON training event in Cascais © PLATON

In the summer of 2017, a course was conducted in Greece (Marathon), specifically dedicated to PLATON's team, to prepare the members of the partnership to train the teachers in their countries. Inquiry and interdisciplinary learning was introduced during a "Mission to Mars"(Figure 134).

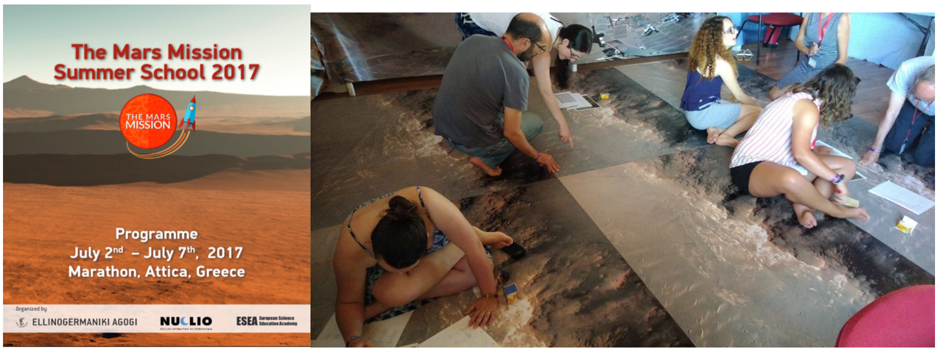


Figure 134 PLATON summer school in 2017 © PLATON

7.1.4. Assessing Inquiry and the 21st century skills

One of the most common statements that teachers present when arguing against shifting their practices to inquiry is their lack of knowledge on how to assess their students in such model. Thinking of this, the final part of the PLATON teacher framework was the creation of a series of tools to help teachers assess their students in terms of understanding of Inquiry, Knowledge acquired, 21st century skills and interdisciplinary understanding of the topic at hands. The assessment methodology was created in line with the recent developments in the educational system in Portugal, as already mentioned in this document where the "Profile of the students when coming out of the compulsory school" (Martins et al., 2017), and in Europe in general according to the OECD publication on "The future of education and skills. Education 2030" (OECD, 2018d) and the European Commission "White Paper on the Future of Europe" (EC, 2017a). We followed the 4Cs of the 21st century skills as pillars for the assessment: Creativity, Critical Thinking and Problem Solving, Communication and Collaboration. The connection of each of these skills with the inquiry cycle was presented in (Doran, P. et al., 2018). A series of assessment tools were created in order to support teachers to individually prepare and follow each student's assessment as well as to adjust their teaching methods according to their students' feedback in a "real-time" process.

7.1.5. PLATON training materials

Finally, in order to ensure the proper application of the teacher training framework, a series of materials for trainers was produced with specific guidelines on how to train teachers in each of the pillars of WIIL (Working with Inquiry and Interdisciplinary Learning) (Doran, P., Doran, R., in prep.). Furthermore, online courses were produced to support the learning of the participants of the training courses and also to be used by other teachers and trainers that could not benefit from the training but wanted nonetheless to benefit from its products.

All the materials created in PLATON are available in the project's website in the e-Agora, where everything is organized and freely accessible (Figure 135).

Figure 135 PLATON eAgora, the central repository of the project © PLATON

Overall, the project had teachers from all over Europe piloting and validating the different components and activities (Figure 136).

Figure 136 Distribution of teachers that participated in PLATON

Several examples of school implementation of the project can be found in (Doran, P. et al., 2018)

At the end of the training we presented a survey to the participants. A preliminary analysis was made by the end of the project. By the time of the analysis a total of 119 participants replied and these were the main conclusions (Doran, P. *et all*, in prep.). The complete results can be found in Appendix VIII

General WILL methodology (Figure 137):

- Over **90%** of the teachers stated that they had worked in an interdisciplinary way and over **70%** stated that they had some level of usage of inquiry based learning, before they implemented the project,
- The majority of respondents considered that the methodology introduced an improvement to their lessons and also to their teaching style
- **100%** of respondents considered that PLATON's methodology promoted a better attitude towards science in the students.

Interdisciplinary learning:

- The majority of the participants claimed to have understood the purpose and mode of use of the 3D map for science teaching and felt that the big ideas of science were useful to build the student's understanding of the topics addressed in the lessons they created/used,
- **82%** felt that the 3D map allowed them to make more connections
- **88%** managed to synchronize the teaching of related topics with their colleagues, through the 3D Map.
- **88%** found the Big Ideas of Science to provide structure for their student's understanding of science and **89%** consider that it improved their students' understanding of science as a whole, **94%** consider the Big Ideas of Science to be useful for their teaching practice.
- over **90%** of respondents considered to have achieved the learning objectives of their lessons while using the PLATON's interdisciplinary approach,
- **18%** teachers felt that the 3D didn't allow to create more connections because it didn't fit the particular curricular topics, it was not adapted to the age of their students, or was not necessary because the connections were already established in the school, or that is presented less connections than those that the teachers discovered themselves,.

Inquiry Learning

- **90%** of the participants found the inquiry components useful for their teaching practice.
- **40%** mentioned that they had difficulties with some components of inquiry. The reasons presented were: resistance by the students to its use, didn't fit the curricula, lack of time, students had difficulty in being creative, students age and lack of capability.
- **95%** found them useful to increase students' achievements,
- over **90%** stated that they reached the learning objectives foreseen for their lessons,

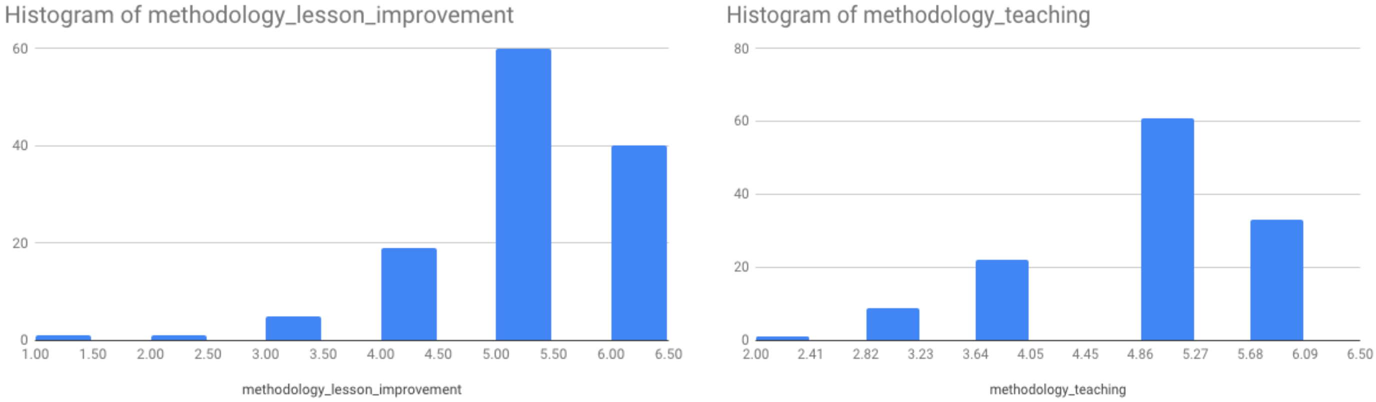


Figure 137 Lesson improvement and Teaching improvement replies

To add to these results the most relevant achievement of the project can be seen in the testimonies of teachers after the implementation runs (Doran, P., 2018). It is also important to note that, in order to successfully finalize the training course in Portugal and in the online course for other countries, teachers had to implement the methodology with their students. A fair fraction did much more than this. Several lessons have been created by the teachers, projects shared in the social media and enthusiastic reports kept reaching our emails. In Escola Secundária de Rio Tinto teachers had the opportunity to share the result of their work with the Ministry of Education and were part of an example shared in several meetings across the country[42].

PLATON proved to be a project happening at a very appropriate time. When nations are discussing the importance of 21st century skills and how to equip young generations with the necessary skills for a challenging future, nothing can be more urgent than supporting educators to move towards a different approach for their interactions with the learners. The stage has to be given to students and schools need to become the knowledge hub for innovation, the centre of the communities' efforts and interests for the sake of their own future. The PLATON methodology was introduced to educators by trainers applying precisely the same methodology that the project is proposing. Participants felt confident and empowered to take the necessary steps towards innovation with very tangible results. The model fosters the collaboration among participants and as a consequence of a strong and sustainable network of mutual support. For PLATON, teachers are the key target when we talk about rethinking education. The results show that it was the right investment with a huge return. Once again, the model used to train and support educators proved its value. The roadmap for citizenship adopted by Portugal (DGE, 2017) has now a few more prepared followers and active promoters.

[42] http://www.aert3.pt/index.php/destaques/679-dia-da-inovacao-em-educacao

Conclusion

We should not forget that the true purpose of education is to make minds, not careers (Hedges, 2009).

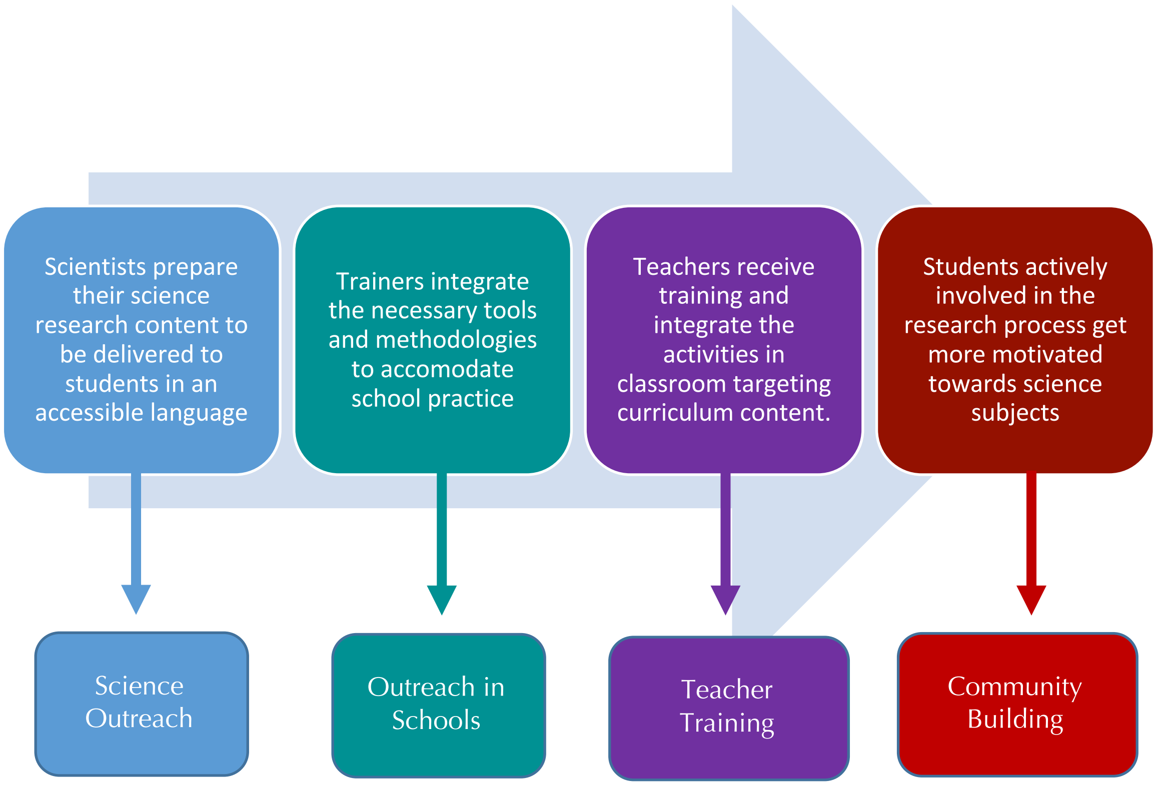
Behind the reason for this thesis is the deep-rooted vision that with education we can change the world for a better place. This can only be achieved if humans are literate people, in all fields of expertise. But science holds a special place in this endeavour. Science is Universal, science requires cooperation between nations, the understanding of nature and us. Science holds in itself the secret of our origins and our possible future. Science requires critical thinking and creativity, awareness and interdisciplinary vision. A science literate person is better prepared to make educated choices and take advantage of the future that is yet to come. The ambition with the work here presented was to document the necessary steps to make the work of teachers meaningful for students learning in a deep and fruitful way.

Hypothesis and Results

The initial hypothesis and the associated scheme studied in this project were the following :

Hypothesis – When scientists produce resources for students related to their research in a user-friendly language and this material is associated to the necessary tools and methodologies to be delivered in teacher training events, teachers will feel confident to integrate them in their lessons, while following curriculum content and actively engaging their students in the research process.

This was the initial proposal with the following scheme:



Each part of the hypothesis was studied following a specific path and tried to answer specific questions that emerged from the initial hypothesis. A series of initial questions were raised and each one was explored in the different chapters:

The work of scientists as promotors of their research to the public in general and its impact
→
What is the impact of science outreach as a mechanism to bring modern research to everyday lessons?

In **chapter 2** some examples of well succeed outreach efforts were presented. The International Year of Astronomy 2009 was one of them. Having reached millions of people around the globe the event was one of the most successful international year ever, in the numbers of people reached and the numbers of countries involved. It is something that will be remembered by many and that left behind long-lasting legacies. Yet most of the grand moments of the event were concentrated in that year and can't be repeated, they can be remembered but not replicated by many. New generations or the ones that were not somehow touched by the event will not be touched by its celebration moments, but they might be by its legacy. Scientists involved in the celebration most probably continued with their mission to disseminate their work, many amateur astronomers continued and will continue promoting star parties and astronomy tools and resources produced during the year will continue to be used as a mean to inspire students for astronomy topics. But in my humble opinion, the strongest legacy are the teachers that have been trained during the year. Those are the ones with the capability of replicating their experience over and over again. In Portugal over 300 teachers received training on the use of cutting-edge tools and resources for science teaching and echoes of their use keep arriving in our emails. From scientists through trainers to teachers and students is one of the most important living legacies of IYA2009.

Outreach activities can be very powerful with very tangible results. But if the impact of public outreach activities can be imposing in numbers of people reached, they also have an **impact that is limited in time**. It is mostly through teacher trainings that we reach the desirable long-lasting results. Even those efforts that have as an outcome user friendly tools and resources for research in classroom have a difficult time to reach the target audience if training is not present. Lots of new materials are developed and made available online every year. What makes them thrive in the hands of teachers and eventually reach the students is the efforts to train educators for their use.

The work of a scientist that acts as a partner of schools and bring their research directly to the hands of students →
What is the impact of scientists working directly with students by involving them in hands-on experiences about their research topics?

In **chapter 3** a series of well succeeded experiences were presented. Each of them with different levels of impact, some of them still enduring over time. Every scientist should devote part of their time to work with teachers and students. Students gain a completely different view of science and their attitude towards this domain acquire a new dimension. In the case of the "Martians of Brandoa" teachers continues to collaborate with scientists and to use with her students many of the activities she learned during the implementation of the activities. The IASC program is another successful story were teachers trained are still participating in the yearly campaigns. These examples are a very encouraging sample of successful joint efforts between scientists and schools and with a long-lasting effect as well. These were the first hints for what is necessary in order to ensure sustainability of the outreach and education efforts. **The sustainability component is clearly present in these examples but the replication and further engagement of other peers, up to now, was not so evident**.

The potential of such enterprises is immense. However, without trained educators, capable of replicating the experiments, they are confined in space and time, hardly replicable and require a strong support of scientists.

The mission of teacher trainers to aggregate the scientific knowledge with the necessary methodology to ensure its usability in classroom and during the preparation of educators
→
What is the impact of teacher training to the integration of modern research in their lessons?

After witnessing the effect of the projects described in **chapter 3** it became obvious that the road towards innovation and research in classrooms had to go through teacher training opportunities. This was the secret behind the sustainability and continuity of certain efforts such as robotic telescope observing, asteroid search and other efforts. However, it also became obvious that one instance of training was not enough for most teachers participating in our training events. Our experience also made it clear that other obstacles could hamper the implementation process, such as lack of support of colleagues, fear of failing when presenting the new feature to students, lack of support from the local community etc. Step by step all the ingredients to support educators face their own lack of knowledge, skills and specific competence were put in place.

In the Black Holes in my School experience for instance, the main aim was to introduce the research in classroom activities as a mean to explore topics such as: gravity, Newton's Laws, Kepler's Laws, etc. The objective was to start from the research in the field, describe its steps in a layman language and facilitate the reproduction of the discovery of such an object with a simple exercise. The assumption was that, provided a complete training and support mechanism was in place, teachers would be encouraged to integrate this research as part of their lessons. The hands-on research experience combined with the integration of *the Inquiry Based Learning* should collect positive results towards their attitudes for science related topics. The road was not so smooth and the scope of the words "Teachers Professional Development" took a completely new meaning. When inviting teachers, and students, to step out of their comfort zone much more than properly produced training material and support is necessary.

Teacher training is a mean to reach an end: improve the knowledge literacy and competence profile of students. If this is not achieved, in my opinion, a training can't be considered a success. Any professional development for teachers should have as its main goal improving learners' experiences. The experience with teachers participating in the different projects was that a minimum of three to four sessions were necessary in order to see the proposed tools, resources or methodology reaching the hands of students. The model adopted included the scheme of visionary workshops, training sessions, workshops for teachers and students at schools, practice reflection workshops, more training opportunities in a continuum cycle of events (Figure 138).

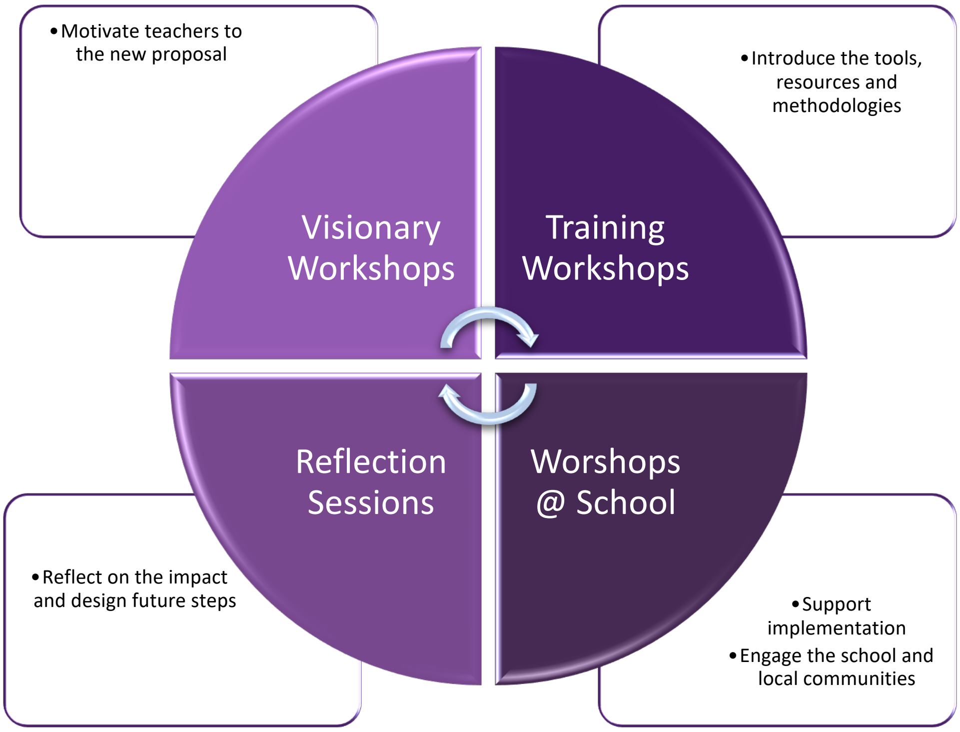


Figure 138 Support model adopted to bring innovation to classrooms

The visionary workshops were the first encounter of teachers with the "product" being proposed. During these events we had the opportunity to understand what were the necessary efforts in order to accommodate the specific needs of each team of teachers, what components were interesting and perceived as useful, which parts were foreseen as challenging, etc. The training events were built taking into consideration the information collected during the visionary workshops. The workshops at schools served several purposes: promote awareness related to the project to members of the schools community; dissolving potential barriers; spark the interest of the students by exposing them to the material and opportunities being introduced during the training courses and support teachers during their first implementation trial; present the innovative approach to parents and other members of the local community in order to share with them the importance of innovation being brought to the hands of the students and future opportunities this might bring. The scheme was very successful in terms of engagement of educators and implementation in schools and was later adopted by several partners of the projects presented in **chapter 4**.

The recipe worked very well with less complex proposals, where the comfort zone of educators involved was not too far from the desired outcome. However, as presented in **chapter 5,** if the topic being introduced encompassed several new components (content knowledge, technical knowledge, methodological expertise), then the process described was not enough, something more was necessary. Despite the fact that teachers participated in the online training event, benefited from online continuous support, workshops at schools and reflection on the project, only a few educators applied the process with their students. **The lack of support from the school heads, the lack of support from peers in many cases and the lack of space within the school allocated time to implement the project (in this particular case, "Black Holes in my School") were strong obstacles.**

Within the scope of this research there was no time, neither the existing conditions at schools at the moment were appropriate, for a more in depth understanding of what would be necessary to have teachers embracing this type of research with their students. As presented in **chapter 1**, the existing education policy at the time of implementation of "Black Holes in my School" was not at all beneficial for the introduction of innovative practices involving student centred learning and technology enhanced objectives. A new trial of implementation of similar proposals, this time using not only black hole candidates but also exoplanets will be proposed to teachers/schools during the school year of 2019/2020. The new education policy in place in Portugal is very favourable for such endeavour. The collection of success stories retrieved in the framework of Go-Lab, the project presented at **chapter 6**, and due to the possibility of retrieval of qualitative data, enabled a more in-depth study on the necessary steps to empower educators to bring innovation to classroom. The model proposed in Figure 138 appeared initially to be enough to ensure classroom implementation runs but in fact, when trying to reach more teachers, not only the self-motivated ones or the ICT confidents, extra measures were necessary/desirable. This reflection gave birth to the "**5 Pillars of Community Building**".

From the description of these efforts it is clear that training and supporting educators is a very demanding and time-consuming task, but a very necessary one. But if we are to reach all teachers in the world, we need to invest in a cascade effect where teachers can train and empower other teachers. To this end we had to understand what was necessary to bring educators from the beginner's stage to a stage of pilot teacher, a teacher that master the use of a certain tool, resource and/or methodology and is capable of training other colleagues. This gave birth to the "**Competence Profile of Go-Lab Teachers** Table 8**.** Although created specifically for a Go-Lab teacher it can be used as a general framework of teachers being trained on the use of student-centred TEL models. With those ideas in place we had still to understand the proper way to motivate and prepare educator to change their expository practice to a student-centred model. The vast majority of the teachers trained integrated some components of it in their practice but their full vision on how to migrate from a teaching practice to a student learning focus was fragmented. So, in **chapter 7** the toolkit created for PLATON was presented. A user friendly resource to help migration from one model to the other. The success was notorious and finally all ingredients for a success story were in place. The project was implemented at the same time as the freedom to adopt student centre models arrive to schools, which helped us reach the desirable outcome.

Innovation in classroom and modern science can only reach students if the proper amount of support is provided and frequently this is synonymous with more investment in the workforce. In the majority of projects devoted to education there is a lot of focus in the development of tools and resources and frequently the workforce necessary to train and support educators for its use is not secured. It is usually seen as something that institutions should be doing from their own funds and resources or should be supported by education authorities' own funds. I don't have numbers or references to validate this claim but frequently this is not the case. I can also claim that limiting the investment to the development of tools and resources might seem like a cheaper solution but frequently, in particular when dealing with TEL, all the products become outdated or even obsolete in a timeframe of a few years. **The investment in improving the competence profile of a teacher has a long-lasting effect and will eventually reach hundreds of not thousands of students during the professional career of the teachers involved.**

The role of a teacher as facilitator of learning
What is the impact of a trained teacher on the motivation of students for science subjects?

Across this document several examples of impact on students were presented:

- The complete shift in attitude and motivation demonstrated by the "Martians of Brandoa", the thrill invading the lives of students that find new asteroids (**chapter 3**),
- The joy of students when making an image using a robotic telescope, while presenting their research on light pollution to a mayor (**chapter 4**),
- The surprising look of students when realizing they just simulated the discovery of a black hole candidate, the pride of the swiss student whose name will appear in a scientific paper (**chapter 5**),
- The joy of students using remote labs and being able to explore their lesson with a high degree of freedom (**chapter 6**)

In **chapter 5** a few results were presented that highlighted the increase in motivation of learners and in **chapter 7** the perception of educators related to the motivation of their students was also discussed. All these and more examples can be reported but a proper study on their motivation was very hard to get. It would have been necessary to take pre and post questionnaires with a statistically valuable cohort of students. This part of the hypothesis will have to be validated during future studies now being prepared.

Design Thinking for the Future

Towards the end of the research presented in this thesis it became clear that more ingredients would be necessary to improve the results of our actions and better understand the diversity of results we achieved. The 5 pillars of community building and the competence profile of teachers were missing a very important component, the community itself. As the research progressed it became clear that, as already suspected, there would never be a single solution to each school, each teacher and each student. As trivial as it might seem, when one has been educated in the traditional way, where a successful student is measured against a cohort of peers, it is sometimes difficult to see the obvious. We are all different, we all have different "super powers", we all have different tastes and aptitudes. If we forget this then the chances of a successful teaching and learning experience can be endangered. The moment we realize that the success stories are individuals and have to be treated as such, then we understand that the roadmap has to be tailored to each individual, then the opportunities start to multiply. This is something that has been understood by marketing specialists for ages and to accommodate this reality, a smart methodology is used to understand customers and to build the roadmap for the success of their business: Design Thinking.

<u>Design thinking</u> is a modern non-linear approach to problem solving. It is about observing people's behaviour, immersing into the way they live and finding what aspects of their lives could be improved. Based on those observations, designers come up with ideas which are quickly turned into prototypes. Designers test, draw conclusions, make adjustments and iterate this process until the end-user's needs are fulfilled[43].The process of design thinking follows a series of steps, interconnected and feeding each other: Feel, Imagine, Do and Share[44] (Figure 139.

[43] https://www.strate.education/gallery/news/design-thinking-definition
[44] https://dfcworld.com/SITE

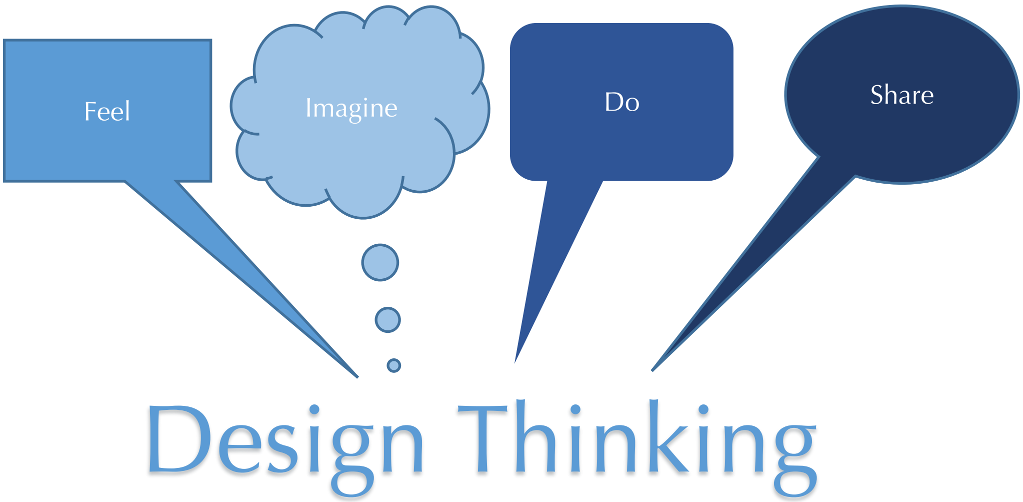


Figure 139 Steps of the design thinking methodology

This is just one of the models, but all are built around the same idea, get to know your audience, imagine what you think would be a suitable solution for them, try the idea and share the results so others can benefit from the findings.

Design thinking in education is a very important and often missing component in schools. Throughout the process presented here what we were in fact doing was getting to know and understand better the teaching profession. Looking back to all we have done it is clear that we had a long process of design thinking. We dived deep into the reality of the life of a teacher, the daily challenges of a school and the difficulties they face to accommodate multiple changes, address innovation needs and care for the personal needs of their community. Each school, each teacher, each student, each member of a school community requires …. no …. deserves to be treated as a unique individual to whom unique solutions apply. Not easy to be done, not cheap, not trivial, but necessary if we really mean to transform schools as the place where the future is positively being shaped.

Teachers are offering to learners the opportunity to improve their content knowledge and their competence profile. This also can't be done to everyone at the same time. Educators need to become experts in design thinking and invest in individual empowerment with unique solutions.

Future Steps

The road travelled so far was very rich and insightful and the experience built have enabled a new level of collaborative work between scientists, teacher trainers, educators and students. While it might seem simple, bringing modern science to the hands of students is not so straightforward. There are many unnecessary obstacles that we unfortunately can't control. Not being simple doesn't mean not achievable, means that more effort needs to be put in place in order to prepare a smooth ride for teachers and students. We understand now the power of community building and the need for a solid competence profile for educators. With this baggage in hand we move now to new adventures. The next steps have the missing components of this research:

- Engagement of the communities during the whole process ensuring the active participation of all relevant stakeholders,
- Getting a deeper insight on the community we are working with by using methodologies such as "Design Thinking",
- Taking advantage of the improvement of the education landscape in Portugal and other countries were educators might be interested to relaunch hands-on research experiences like Black Holes in my School
- Engage students from the very beginning of the process ensuring that pre and post questionnaires are properly delivered enabling a more in deep understanding of their learning path.

Final Considerations

The roadmap described in this document has several building blocks that prepared the way to a better understanding of what is necessary to bring modern science to the hands and minds of students. During the learning journey, that indeed took several years, a lot has changed in terms of education and my personal understanding of it. The technology available to enhance learning greatly improved and now possibilities are far beyond what we can possibly imagine. The cost of digital tools is getting lower and lower and devices can now easily populate classrooms in any corner of the world. But these years also brought the understanding that technology per se doesn't improve learning (OECD, 2015) it is just a tool that when properly used can indeed greatly improve the student's learning experience.

The road provided a lot of wisdom related to educators, their challenges and opportunities, the self-imposed barriers, the lack of team spirit in schools, the lack of mutual support, even the lack of mutual awareness. Schools should better organize themselves and perhaps adopt some of the methods used by companies to create a good and profitable learning environment. Not profitable in terms of currency but in terms of learning experiences, for learners and educators equally. Teachers are often swamped with paperwork and claim not to have time to invest in getting to know their audience on an individual basis. Student's view schools as a place they have to go as if this was their duty and not their right.

The path also presented a reality were communities are completely detached from their education centres, the schools. The usual schools are self-centred and often assumes a role of the expert in the field. But an expert that doesn't reach out, stays put waiting for those willing to take the opportunity to come and seek for the knowledge they have to share.

These “houses of knowledge” have to become the hubs of their local community, taking advantage of the expertise existing within its members and supporting the existing needs. Investing in the training and support of educators is synonymous with investing in humankind future, a very profitable investment. Being such an important profession, my personal view is that individuals taking this gigantic task need to have a vocation and talent for this. More important than content knowledge and awareness of different pedagogical models is the will to embrace the necessary challenges with resilience, patience, tolerance and respect for the humans they are about to influence. Not everyone can be an educator!!!

Education is a place and space within ourselves were the magic of becoming a better us happens every day. Learning is a privilege and a right and should be recognized as such by every student entitled to have a place in a learning house with a facilitator accompanying their days. Teachers have to understand that they are the ones deciding who are the future leaders of our planet, those talented kids whose hidden power was nurtured. Every child is a hidden treasure and hold in them the potential to be whatever they want to be. Educators have to decide how they want children to perceive their learning goal. Will it be fun and challenging? Full of opportunities and obstacles to be overcome? Will it be a place of amazement, of continuous discovery or will it be a boring place completely detached from reality of our daily lives? Better still, will it be an opportunity to pave the way to a successful future or a place to constantly visit the past without the opportunity to see the new and to envision what is there to come?

Content knowledge is at a distance of a click, personalized learning spaces, adaptable to any special need, flourish online. All possible choices of learning path can be pursued with the support of a virtual tutor in a synchronous or asynchronous manner. A student can choose which university will facilitate their graduation without leaving the comfort of their homes. Schools need to accept this new reality and completely transform, redesign their spaces. Open spaces where collaboration and cooperation are part of student’s everyday experience have to invade the knowledge houses. Teachers have to assume the role of facilitators and give the floor to students as designers of their own trajectory. A place where students develop their own project, in collaboration with their colleagues, self-regulating their attitudes and responsibilities. A space where technology is used as supporting tools. Schools as hearts of their communities should be the aggregators of opportunities for those in need of support and the hub benefiting from all the existing knowledge and skills.

Changing education is synonymous with changing the world. Living in the 21st century is a privilege for many but a time of uncertainty and fear to many more. Acknowledging that the main pillars of being humans are under threat, that our understanding of being humans are menaced by the lack of cultural, historical, scientific literacy, to name a few, is a shame and completely unacceptable. We can’t turn our heads as if these problems are not our own and hide behind a lame excuse that there is nothing that we can do about it. Each individual has a responsibility towards the greater good. As Malalah Yousafzai, so wisely said: One child, one book, one teacher, one pen, can change the world” (Winter, 2014).

The answer is there: “Change the world teacher by teacher. We can’t reach all the children in the world. But with a well-orchestrated effort our message can go from hand to hand until all educators in the planet have the opportunity to be their possible best.”.

I had the privilege to share time and space in this planet with very wise people. I can’t refer to the one that taught me most, but one speech touched me deeply. Gerard McHugh, coordinator of one project in which I participated said: “Be a teacher, be an amazing teacher, but most important than all, be you, be an amazing you". **This is precisely the mission of every teacher to help students be the best they can be**. I hope that the work described here will serve the purpose to convince at least a few that by empowering and supporting each other the world will be a safe place. After all it is all about people and the choices, we all make. I made a very important choice a few years ago, to devote my life to improve education worldwide, to empower and inspire educators. In this document, I shared some of the moments of my journey so far. I apologize if important pieces are missing or the efforts that made the journey so rich are not properly accredited. It is the sum of all amazing creatures that invaded my days that made the journey possible and so unique.

During all the years working with teachers all over the world and in particular in Portugal I could witness the enormous goodwill and amount of effort invested by educators to provide the best possible future to their students. During easy or more rough times their resolve would not be weakened. To those champion teachers, here and there, that devote their lives to the future of mankind, a sincere thank you and the wish that many more will be inspired by you and your fantastic example. To teachers, the most important profession in the world!!!

Acknowledgments

Most people at some point of their lives have a wish to change the world to a better place. I am one of the few who really got much more than I have ever dreamed and have as my daily work the opportunity to help people improve their lives. The privilege to be surrounded by amazing and very special people that accompanies me every day.

I start by thanking my two beautiful daughters and my grandson who were since the day they were born my source of strength and inspiration. They supported me and convinced me never to give up no matter how hard or unfair the path was. They are my heart and soul.

I thank my mother who was a unique human being that taught me how to be strong in the face of adversity and how to face the world always with a smile and positive attitude no matter the size of the problems we had to face.

I thank my true companion and best friend who kept beside me in some very difficult times and have never let me give up. Probably the most patient person in the world.

I thank all my journey companions from NUCLIO who always support me in spite of all the crazy load of work we have or highly demanding decisions I take. Since the day our association was created, they have been by my side in easy and difficult times.

I thank my supervisors who carefully guided me to a successful ending of this PhD, in particular Prof. João Fernandes who convinced me to accept the challenge. I also would like to thank everyone that contributed for this journey but a special reference to Prof. Piedade Vaz for the many hours of support and exchange of ideas and Dr. Fraser Lewis for his great support while developing the Black Holes in my School Project. I thank all my work colleagues from all the projects we participated for the healthy exchange of experiences.

Having a PhD degree was never important to me but achieving this milestone in my life was the proof that when there is a will there is always a way. I devote this successful ending, or beginning to my father, to my brother and to my mother wherever they are. Thank you for being so special people and lucky me for having had you around me for a while. May the journey continue.

"You cannot hope to build a better world without improving the individuals. To that end each of us must work for his own improvement, and at the same time share a general responsibility for all humanity, our particular duty being to aid those to whom we think we can be most useful."

Marie Curie

References

Adesope, O. O., Austin, B., Bélanger, J., French, B., Gotch, C., Hidalgo Hidalgo, M. L., & Ben Jensen, Simon Normandeau, Mathilde Overduin, José Ignacio García Pérez, Heather Price, Charles Ungerleider, Kristen Weatherby and Zohreh Zadeh with help from Michael Davidson, Francesca Borgonovi, Tracey Burns, Dirk Van Damme, Tadakazu Miki, Gabriella, A. S. and P. Z. (2013). *TALIS 2013 Results*. http://doi.org/10.1787/9789264196261-en

Ainsworth, H., & Eaton, S. (2010). *Formal, non-formal and informal learning in the sciences*. *Sciences-New York*. http://w.eatonintl.com/www.eatonintl.com/Research_files/Formal,%20non-formal%20and%20informal%20learning%20in%20the%20sciences.pdf

Alberta Learning. (2004). Focus on inquiry: A teacher's guide to implementing inquiry-based learning. http://blogs.*ubc*.ca/stevemcg/files/2014/09/Focus-on-Inquiry-teacher-guide.pdf

Amany Annaggar. (2016). *Inspiring Science Education Validation Report D8 . 3 Inspiring Science Education Validation Report and Recommendations*.

Archer, L., Osborne, J., DeWitt, J., Dillon, J., Wong, B., & Willis, B. (2013). Young people's science and career aspirations, age 10 – 14. *King's College London Department of Education & Professional Studies*, 40.

Asbell-Clarke, J., Pack, H., Pennypacker, C., & Toler, D. (1996). Hands-on Universe: Bringing Astronomical Explorations to the Classroom. In *Astronomical Society of the Pacific* (pp. 158–160).

Bacigalupo, M., & Cachia, R. (2011). Teacher Collaboration Networks in 2025: What is the role of teacher networks for professional development in Europe. *Notes from the Workshops Held on the 6th and 7th*, (June). http://doi.org/10.2791/69124

Baeta, P., & Pedro, N. (2017). Práticas Educativas nas Salas de Aula do Futuro: análise focalizada nas metodologias de ensino-aprendizagem TEL@FTE-lab View project TEL@FTELab: Work Package 2-Design of Future Teacher Education Lab View project, (December). Retrieved from https://www.researchgate.net/publication/316787717

Barber, M., & Mourshed, M. (2007). How the world's best-performing schools systems come out on top. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:How+the+World's+best+performing+school+systems+come+out+on+top#0

Bishop, J. L. (2013). The Flipped Classroom : A Survey of the Research the Flipped Classrom : A Survey of the Research.

https://www.researchgate.net/publication/285935974_The_flipped_classroom_A_survey_of_the_research

Bogner, F. (UBT), Schmid, S. (UBT), & Dieser, O. (UBT). (2013). *The PATHWAY to Inquiry Teachers ' Guidelines*. Retrieved from http://www.pathway-project.eu/sites/default/files/D3.3_the_PATHWAY_to_IBSE_ENGLISH_0.pdfBourne, V. (2018). Realizing 2030 : A Divided Vision of the Future, 1–10.

Bultitude, K. (2011). The Why and How of Science Communication. *Science Communication*, 1–18. http://doi.org/10.2331/suisan.80.255

Burris, J. E. (2012). It's the teachers. *Science*, *335*(6065), 146. http://doi.org/10.1126/science.1218159

Burrows D. N., Racusin J., Morris D. C., Roming P., Chester M., LaVerghetta R., Markwardt C. B., Barthelmy S. D., 2005, ATEL 547

Bybee, R., Taylor, J. a, Gardner, A., Van, P., Powell, J. C., Westbrook, A., … Knapp, N. (2006). The BSCS 5E Instructional Model : Origins and Effectiveness. A Report prepared for the Office of Science Education and National Institutes of Health. *Bscs*, (June), 80. http://doi.org/10.1061/(ASCE)HE.1943-5584.0001189.

Bybee, R. (2010). *The teaching of science: 21st century perspectives*. Retrieved from http://books.google.com/books?hl=en&lr=&id=T416plklYC4C&oi=fnd&pg=PR5&dq=The+Teaching+of+Science:+21st+Century+Perspectives&ots=DMlb90A887&sig=QeW1WTDSf998hycs3XXD1h3MzGU

Coelho, A. A. (2016). "O processo de implementação do currículo de ciências físicas e naturais numa escola de Lisboa: perspetiva dos professores.". In Interacções. https://doi.org/10.25755/int.8730

Community Places. (2014). Community Planning Toolkit: Community Engagement, 24. Retrieved from http://www.communityplanningtoolkit.org/sites/default/files/Engagement.pdf

de Jong, T., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: The Go-Lab federation of online labs. *Smart Learning Environments*, *1*(1), 3. http://doi.org/10.1186/s40561-014-0003-6

de Jong, T. (2016). Technological Advances in Inquiry Learning. *Science Magazine*, *312*, 532–533.

Delicado, A. (2006). Os museus e a promoção da cultura científica em portugal. *Sociologia, Problemas E Práticas*, *51*, 53–72.

Deloitte. (2018). Survey of Schools : ICT in Education. https://ec.europa.eu/digital-single-market/en/news/survey-schools-ict-education

Delors, J. (1996). *Learning: The Treasure Within*. http://www.unesco.org/education/pdf/DELORS_E.PDF

Dewey, J. (1910). How we think. http://doi.org/10.1037/10903-000

DGE. (2017). *Estratégia Nacional de Educação para a Cidadania*. Retrieved from http://www.dge.mec.pt/estrategia%0A-nacional%0A-de-%0Aeducacao-%0Apara-%0Acidadania

DGEEC - Direção Geral de Estatísticas da Educação e Ciência, & Direção de Serviços de Estatística da Educação, D. (2016). *Modernização Tecnológica das Escolas 2014/2015*. Direção Geral de Estatísticas da Educação e Ciência.

DGEEC - Direção Geral de Estatísticas da Educação e Ciência, (2018). *Educação em Números, 2018*.

Doran, P., Tsourlidaki, E., Doran, R., Latas, J., Kypriotis, E., Papaevripidou, M., … Bergh, A. (2018). *PLATON - Roadmap Towards Innovation - A step-by-step guide for teachers*. Ellinogermaniki Agogi. Retrieved from http://platon-project.eu/sites/default/files/PLATON ROADMAP-all-high.pdf

Doran, P., Doran, R., Tsourlidaki, E., Latas, J. *WIIL - Working with Inquiry and Interdisciplinary Learning, - in prep.*

Doran, R., Naze, Y., & Heward, A. (2010). Europlanet Best Practice Guide.

Doran, R., Correia, N., Guerra, R., & Costa, A. (2012). Dark Skies Rangers - Fighting light pollution and simulating dark skies. *Proceedings of the International Astronomical Union*, *10*(H16).

Doran, R., Melchior, A.-L., Boudier, T., Pacôme, Delva, Ferlet, R., Roberts, S. (2012). Astrophysics datamining in the classroom: Exploring real data with new software tools and robotic telescopes. *ArXiv Preprint*, 10. Retrieved from http://arxiv.org/abs/1202.2764

Doran, R. (2013). Building Blocks of our Future. In A. Lazoudis (Ed.), *Discover the Cosmos Conference - e-Infrastructure for an Engaging Science Classroom*. Ellinogermaniki Agogi.

Doran. (2014). Building bridges and creating communities with innovative technologies. *Proceedings - IEEE 14th International Conference on Advanced Learning Technologies, ICALT 2014*, 724–726.

Doran, R. (2014a). O Programa " Global Hands-on Universe " e o ensino de Astronomia. In Marcos Daniel Longhini (Ed.), *Ensino da astronomia na escola: concepções, ideias e práticas* (pp. 67–81). Campinas: Átomo.

Doran, R. & Kypriotis, E. (2014b). *A Methodology for organising the eLearning tools and resources - Inspiring Science Education*.

Doran, R., & Sotiriou, S. (2015). Report on Development of the Virtual Go - Lab User Community - V1.

Doran, R., Koslowsky, J., Rodriguez, M., Sotiriou, S. (submitted). Looking back to 4 years promoting IBL among teachers: the adoption of Go-Lab by the Portuguese educative community. *Revista Educar*.

Doran, R. (n.d.). A RIQUEZA DE UM PAÍS MEDIDA PELA LITERACIA CIENTÍFICA. In *Comunicação de Ciência: das Universidades ao grande público* (pp. 26–49).

Doran, R. *Digital Schools of Europe - The case of Portugal, in prep*

Dourado, L., Leite, L., & Morgado, S. (2016). In-Service Science Teacher Education in Portugal : An

Analysis of The Short Courses Available. *The Turkish Online Journal of Educational Technology – TOJET*, (December), 1505–1516.

Dutton, E., Winterbottom, F., Regan, M., Wilison, E., Vergou, J., & Kapelari, A. (2013). *INQUIRE: A review of the literature on Inquiry-based Science Education in outdoor contexts* Esperança, T., & Fernandes, J. (2013).

Elliott, R., Clayton, J., & Iwata, J. (2014). Exploring the use of micro-credentialing and digital badges in learning environments to encourage motivation to learn and achieve Theoretical framework. Rhetoric and Reality, 703–707.

Euan Henderson (1977) The Growth of In-Service Education and Training in the U.K., Journal of In-Service Education, 3:3, 163-174, DOI: 10.1080/0305763770030302

European Commission. (2005). Eurobarometer Spezial 2005 Nr. 224 Europeans, Science and Technology. *Science and Technology*, (February).

European Commission, (2007). Key Competencies for Lifelong Learning: European Reference Framework, 1–12. Retrieved from http://bookshop.europa.eu/en/key-competences-for-lifelong-learning-pbNC7807312/

European Commission, (2010), Eurobarometer, Science and Technology Report, (June).

European Commission, (2013). Opening Up Education: Innovative Teaching and Learning for all through new Technologies and Open Educational Resources, 1–13. http://doi.org/10.2766/77543

European Commission (2013a). Responsible Research and Innovation (RRI), (November). http://ec.europa.eu/research/swafs/pdf/pub_science_education/KI-NA-26-893-EN-N.pdf

European Commission. (2014). *Eurobarometer: Public Perceptions of Science , Research and Innovation*. http://doi.org/10.2777/95599

European Commission (2015). *Sience Education for Responsible Citizenship*. Luxembourg: Offices for Official Publications of the European Communities. http://doi.org/10.2777/12626

European Commission/EACEA/Eurydice. (2015a). *The teaching profession in Europe - Practices, Perceptions and Policies*.

European Commission (2016). The Future of Work Skills and Resilience for a World of Change EPSC Strategic Notes the World of Work Has Always Evolved Opportunities, Disruptions and Transitions. *EPSC Strategic Notes*, (13), 12. Retrieved from http://ec.europa.eu/epsc/sites/epsc/files/strategic_note_issue_13.pdf

European Commission (2017). Reflection Paper on Harnessing Globalisation. *Com(2017) 240*. https://ec.europa.eu/commission/sites/beta-political/files/reflection-paper-globalisation_en.pdf

European Commission. (2017a). *White Paper on the Future of Europe*. Retrieved from https://ec.europa.eu/commission/sites/beta-political/files/white_paper_on_the_future_of_europe_en.pdf

European Commission, (2018). *Key Competences for Lifelong Learning*. https://ec.europa.eu/education/resources-and-tools/document-library/key-competences-for-lifelong-learning_en

European Commission, (2018a). *Education and Training MONITOR 2018*. http://doi.org/10.2766/332592

European Commission, (2018b). Flash Eurobarometer 466 Briefing note The European Education Area Fieldwork April 2018 May 2018 Survey requested by the European Commission .

European Commision. (2018c). Digital Education Action Plan 2. Retrieved from https://ec.europa.eu/education/sites/education/files/digital-education-action-plan.pdf

European Commission/EACEA/Eurydice. (2018d). Teaching Careers in Europe: Access, Progression and Support. http://doi.org/10.1097/MAO.0b013e3182040b03political/files/white_paper_on_the_future_of_europe_en.pdf

Frade, A., Doran, R., & Fernandes, J. (2011). Evaluating the Impact of the International Year of

Astronomy 2009 in Portugal, (11), 2009–2012.

Lewis, F. (2018). FTP and NSO: Astronomy With (Several) Robotic Telescopes, *1*(1), 1–5. Retrieved from http://arxiv.org/abs/1807.00762

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. http://doi.org/10.1073/pnas.1319030111

Gaible,E., & Burns, M., (2014). *USING TECHNOLOGY TO TRAIN TEACHERS*. (M. Trucano, Ed.) (ICT and Ed). Retrieved from www.infoDev.org

Gilbert, I. (2010). *Why Do I Need a Teacher when I've Got Google?: The Essential Guide to the Big Issues for Every 21st Century Teacher*. Routledge

Gillet, D., Tijani, B., Beheton, S., Farah, J. C., Dikke, D., Noutahi, A., … Gavaud, C. (2019). Promoting and Implementing Digital STEM Education at Secondary School in Africa. In *EDUCON 2019*.

Goertzel, T. (2010). Conspiracy theories in science. *EMBO Reports*, *11*(7), 493–499. http://doi.org/10.1038/embor.2010.84

Gomez, E. L., & Fitzgerald, M. T. (2017). Robotic Telescopes in Education, 1–42. http://doi.org/10.1080/21672857.2017.1303264

Gray, P., & Riley, G. (2015). Grown Unschooler's Evaluation of Their Unschooling Experiences. *The Journal of Educational Alternatives*, *4*(2), 8–32.

Harlen, Wynne. Assessment & inquiry-based science education: Issues in policy and practice. Global Network of Science Academies, 2013.

Harlen, W., & Bell, D. (2010). *Principles and big ideas of science education*. Retrieved from http://cmaste.ualberta.ca/en/Outreach/~/media/cmaste/Documents/Outreach/IANASInterAmericasInquiry/PrinciplesBigIdeasInSciEd.pdf

Hedges, C, (2009). *Empire of Illusion: The End of Literacy and the Triumph of Spectacle* - Bold Type Books.

Higgins, S., Cordingley, P., Greany, T., & Coe, R. (2015). Developing Great Teaching. Teacher Development Trust.

Hilton, M. (2010). *Exploring the Intersection of Science Education and 21st Century Skills*. http://doi.org/10.17226/12771

IFTF. (2017). *The next era of human-machine partnerships*. Retrieved from https://www.delltechnologies.com/content/dam/delltechnologies/assets/perspectives/2030/pdf/SR1940_IFTFforDellTechnologies_Human-Machine_070517_readerhigh-res.pdf

International Council for Science. (2011). *Report of the ICSU ad-hoc review panel on science education Council for Science*. Paris. Retrieved from www.icsu.org

Kampylis, P., Punie, Y., & Devine, J. (2015). *Promoting Effective Digital-Age Learning - A European Framework for Digitally-Competent Educational Organisations (ES)*. http://doi.org/10.2791/54070

King, H., Nomikou, E., Archer, L., & Regan, E. (2015). Teachers' Understanding and Operationalisation of 'Science Capital.' *International Journal of Science Education*, *37*(18), 2987–3014. http://doi.org/10.1080/09500693.2015.1119331

Klaus Fahle. (2008). *Grundtvig Mobility - How to organise training courses for an international audience A handbook on project management*.

Liebowitz, D., González, P., Hooge, E., & Lima, G. (2018). *OECD Reviews of School Resources*. *World Bank Publications*. http://doi.org/http://dx.doi.org/10.1787/9789264245891-en

Lor, R. (2018). *Design Thinking in Education : A Critical Review of Literature*.

Loucks-Horsley, S., & Olson, S. (2000). *Inquiry and the National Science Education Standards:: A Guide for Teaching and Learning*. Retrieved from http://books.google.com/books?hl=en&lr=&id=ucWaAgAAQBAJ&oi=fnd&pg=PR10&dq=Inquiry+a

nd+the+National+Science+Education+Standards:+A+Guide+for+Teaching+and+Learning&ots=Ol4jSJY2w8&sig=TNQ93ZdQxI07WTxSMix4F2Dmxbc

Martins, G., Gomes, C., Brocardo, J., Pedroso, J., Carrillo, J., Silva, L., … Rodrigues, S. (2017). Perfil Dos Alunos À Saída Perfil Dos Alunos. Retive from https://comum.rcaap.pt/bitstream/10400.26/22377/1/perfil_dos_alunos.pdf

Martins, I. P., Peralta, H., & Roldão, M. do C. (2017). Para a Construção De Aprendizagens Essenciais Baseadas No Perfil Dos Alunos, 15. Retrieved from http://dge.mec.pt/sites/default/files/Curriculo/Projeto_Autonomia_e_Flexibilidade/ae_documento_enquadrador.pdf

Mavromanolakis, G., & Doran, R. (2016). Go-Lab Global Online Science Labs for Inquiry Learning at School Annexes to D6 . 7 Report on development of the virtual Go-Lab user community Report on Implementation Activities Phase-C, (317601).

McKee, J. (2009). The 90-9-1 principle: How users participate in social communities, 9–10. Retrieved from http://www.90-9-1.com/

Merchant, G. (2004). *Learning for the Future*. *Handbook of Research on New Media Literacy at the K-12 Level*. http://doi.org/10.4018/978-1-60566-120-9.ch001

Mona Mourshed, Chijioke, C., & Barbe, M. (2010). *How the world's most improved school systems keep getting better*. *McKinsey*. Retrieved from https://www.mckinsey.com/~/media/mckinsey/industries/social sector/our insights/how the worlds most improved school systems keep getting better/how_the_worlds_most_improved_school_systems_keep_getting_better.ashx

Morton, R. (2010). Home education: Constructions of choice. *International Electronic Journal of Elementary Education*, *3*(1), 45–56.

Nationlal Academy of Sciences, (2015). *Science Teachers' Learning: Enhancing opportunities, creating supportive contexts*. (S. Wilson, H. Schweingruber, & N. Nielsen, Eds.). National Academies Press. Retrieved from http://www.nap.edu/catalog/21836

Nerantzis, N. (2016). Integrating Innovative Practices in Secondary Special Educaiton in Greece. In A. Lazoudis & Stephanos (Eds.), *Inspiring Science Education Conference*. Ellinogermaniki Agogi.

Nomikou, E., Archer, L., & King, H. (2017). Building "science capital" in the classroom, *118*(365), 98.

Nunes, I. de O., & Dourado, L. G. P. (2017). Poluição luminosa e educação ambiental: um estudo de caso em Camarate, Lisboa. *Revista Latino-Americana de Educação Em Astronomia*, (24), 1–21. Retrieved from http://repositorium.sdum.uminho.pt/handle/1822/53948%0Ahttp://hdl.handle.net/1822/53948

OECD. (2013). PISA 2012 Results: What Students Know and Can Do (Volume I) (Vol. I). OECD Publishing. http://doi.org/10.1787/9789264201118-en

OECD, (2014). *Education at a Glance 2014: Highlights*. *OECD* http://doi.org/10.1787/eag-2013-en

OECD, (2014a), Talis 2013 Results: an international Perspective on Teaching and learning, oecd Publishing. http://dx.doi.org/10.1787/9789264196261-enOECD. (2016a). *Global competency for an inclusive world*. *OECD*.

OECD, (2015), *Students, Computers and Learning: Making the Connection,* PISA, OECD Publishing. http://dx.doi.org/10.1787/9789264239555-en

OECD. (2016b). *PISA 2015 Results (Volume I): Excellence and Equity in Education* (Vol. I). PAris: PISA, OECD Publishing. http://doi.org/10.1787/9789264266490-en

OECD. (2018a). Curriculum Flexibility and Autonomy in Portugal -an OECD Review Curriculum Flexibility and Autonomy in Portugal - an OECD Review. Retrieved from http://www.oecd.org/education/2030/Curriculum-Flexibility-and-Autonomy-in-Portugal-an-OECD-Review.pdf

OECD. (2018b). OECD SCHOOL USER SURVEY Improving learning spaces together. Retrieved from www.oecd.org/education/innovation-education/centreforeffectivelearningenvironmentscele/

OECD. (2018c). Preparing Our Youth for an Inclusive and Sustainable World: The OECD PISA Global Competence Framework, 43. http://doi.org/10.1074/jbc.M801892200

OECD. (2018d). The Future of Education and Skills: Education 2030. *Oecd*, 23. http://doi.org/10.1111/j.1440-1827.2012.02814.x

OECD (2018e), Teaching for the Future : Effective Classroom Practices to Transform Education, OECD, Publishing, Paris, http://dx.doi.org/10.1787/9789264293243-en.

Orr, D., Rimini, M., & Damme, D. Van. (2015). *Open educational resources A Catalyst for Innovation*. *OECD Publishing*.

Osborne, J., & Dillon, J. (2008). Science Education in Europe: Critical Reflections. A Report to the Nuffield Foundation.(2008), (January). Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Science+Education+in+Europe+:+Critical+Reflections+A+Report+to+the+Nuffield+Foundation#8

Palmeirão, C., & Alves, J. M. (2017). *Construir a Autonomia e a Flexibilização Curricular: Os desafios da escola e dos professores*. Porto: Universidade Católica Editora - Porto.

Paniagua, A., & Istance, D. (2018). *Teachers as Designers of Learning Environments* (Educationa). Paris: OECD. http://doi.org/10.1787/9789264085374-en

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., … Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. http://doi.org/10.1016/j.edurev.2015.02.003

Peinado, S., Mota, J. M., Palomo-Duarte, M., Dodero, J. M., Berns, A., Martellos, S., … Stergiopoulos, P. (2015). Experiences of technology-rich innovation in European schools within the Open Discovery Space project. *Teoria de La Educacion*, *16*(3), 35–56.

Pennypacker, C. (2006). “Uma breve história do Global Hands-on Universe.” Retrieved from http://portaldoastronomo.org/tema.php?id=32

Piaget, J. (1929). *The Child's Conception of the World*. *International Library of Psycology Philosophy and Scientific Method*. Routledge & Kegan Paul Ltd.

Quinn, H. (2012). *A Framework for K-12 Science Education*. *APS March Meeting Abstracts* (National R). Retrieved from http://adsabs.harvard.edu/abs/2012APS..MAR.J2001Q

Redecker, C., & Punie, Y. (2017). *Digital Competence of Educators DigCompEdu*.

Reimers, C., Pointner, T., & Huber, E. (2013). *Discover the Cosmos Validation Report*.

Robinson, K. (2005). How Creativity, Education and the Arts Shape a Modern Economy, (April). Retrieved from http://benefits.nn.k12.va.us/arts/art/ArtsandMinds.pdf

Rocard, M. (2007). A Renewed Pedagogy for the Future of Europe. *Economy and Society*, 29. Retrieved from http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf

Rockstroh, M., Doran, R., 2012, *D2.5 . Initial Discover the Cosmos Demonstratros,* Discover the Cosmos Project.

Russo, P., & Lindberg, L. (2010). *International year of astronomy 2009*. *International Astronomical Union*.

Rutten, N., Joolingen, W. R. van, Haverkamp-Hermans, G. G. N., Bogner, F. X., Kretschmer, T., Stracke, C. M., Polymatidis, D. (2015). A narrative approach to studying the diversification of inquiry learning across instructional settings *International Journal of Education and Development Using Information and Communication Technology (IJEDICT)*, *11*(2), 184–228. Retrieved from https://files.eric.ed.gov/fulltext/EJ1074141.pdf

Sagan, C. (1994). *Pale blue dot: a vision of the human future in space*.

Schleicher, A. (2018). *International Summit on the Teaching Profession Valuing our Teachers and Raising their Status HOW COMMUNITIES CAN HELP*.

Science and Technology Committee. (2017). Science communication and engagement. *Science and*

Technology Committee Eleventh Report of Session 2016-17, (March), 1–36. http://doi.org/10.1787/9789264025387-en

Serra, P., & Galvão, C. (2015). *Evolução Do Currículo De Ciências Em Portugal : Será Bloom Incontornável ?*, *271*(39), 255–271.

Singer, H. (2016). Experiências em educação integral inspirando um novo movimento na Educação Brasileira, *2016*(2013).

Sjøberg, S., & Schreiner, C. (2010). The ROSE project An overview and key findings. *Oslo: University of Oslo*, (March), 1–31. http://doi.org/10.1063/1.4895968

Sotiriou, S. (2011). *The Pedagogy of Inquiry Teaching: Strategies for Developing Inquiry as part of Science Education*.

Sotiriou, S. A. (2014). Large scale school-based technology supported education innovation. *Proceedings - IEEE 14th International Conference on Advanced Learning Technologies, ICALT 2014*, (May), 5. http://doi.org/10.1109/ICALT.2014.11

Sotiriou, S., Riviou, K., Cherouvis, S., Chelioti, E., & Bogner, F. X. (2016). Introducing Large-Scale Innovation in Schools. *Journal of Science Education and Technology*, *25*(4), 541–549. http://doi.org/10.1007/s10956-016-9611-y

Stylianidou, F., Lazoudis, A., Zervas, P., Sampson, D., Kolovou, L., Tiemann, R., … Sotiriou, S. (2015). *Inspiring Science Education Teacher Guide*. (F. Stylianidou, Ed.). Ellinogermaniki Agogi. Retrieved from https://portal.opendiscoveryspace.eu/sites/default/files/ISEGuide/INSPIRING_SCIENCE_TEACHER_GUIDE_EN.pdf

Tasiopoulou, E., Ton de Jong, & Martin, E. (2016). *Integrated validation and evaluation report and recommendations – complete version*.

Tsourlidaki, E., Sotiriou, S., & Doran, R. (2016). The “ Big Ideas of Science ” for the school classroom : Promoting interdisciplinary activities and the interconnection of the science subjects taught in primary and secondary education. *Journal of Research in STEM*, *2*(2), 72–89. Retrieved from http://j-stem.net/wp-content/uploads/2018/04/jstem_vol2_no2_report1.pdf

Tytler, R., & Osborne, J. (2012). Student attitudes and aspirations towards science. In Second international handbook of science education (pp. 597-625). Springer, Dordrecht.

United Nations (2015). *Transforming our World: The 2030 Agenda for Sustainable Development*.

Unesco. (2011). *Unesco ICT Competency Framework for Teachers*. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000213475

Unesco. (2015). *Rethinking Education: Towards a global common good ?* France: UNESCO Publishing. Retrieved from http://www.unesco.org/fileadmin/MULTIMEDIA/FIELD/Cairo/images/RethinkingEducation.pdf

Vaz-Rebelo, P., Doran, R., Almeida, L., Gonçalves, J., & Bidarra, G. (2018). Elementary and Secondary student teachers knowledge and conceptions of Inquiry Based Learning: description and impact of a teacher-training workshop. In *ATEE*.

Vincent-Lancrin, S., Urgel, J., Kar, S., & Jacotin, G. (2019). *Measuring Innovation in Education 2019*.

Vygotsky, L. (1986). *Thought and language*. The Massachusetts Institute of Technology.

Waldrop, M. M. (2013, July). The Virtual Lab. *Nature*, 268–270. Retrieved from https://www.nature.com/polopoly_fs/1.13383!/menu/main/topColumns/topLeftColumn/pdf/499268a.pdf

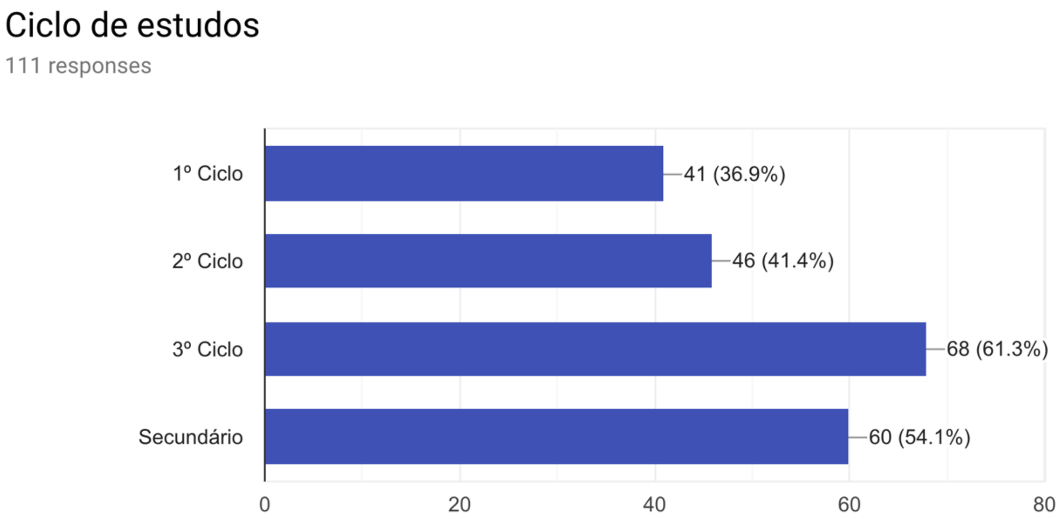
Winter, J. (2014). Malala, a brave girl from Pakistan/Iqbal, a brave boy from Pakistan: Two stories of bravery. Simon and Schuster.

Young Digital Plantet, 2015 , *The Book of Trends in Education 2.0*.

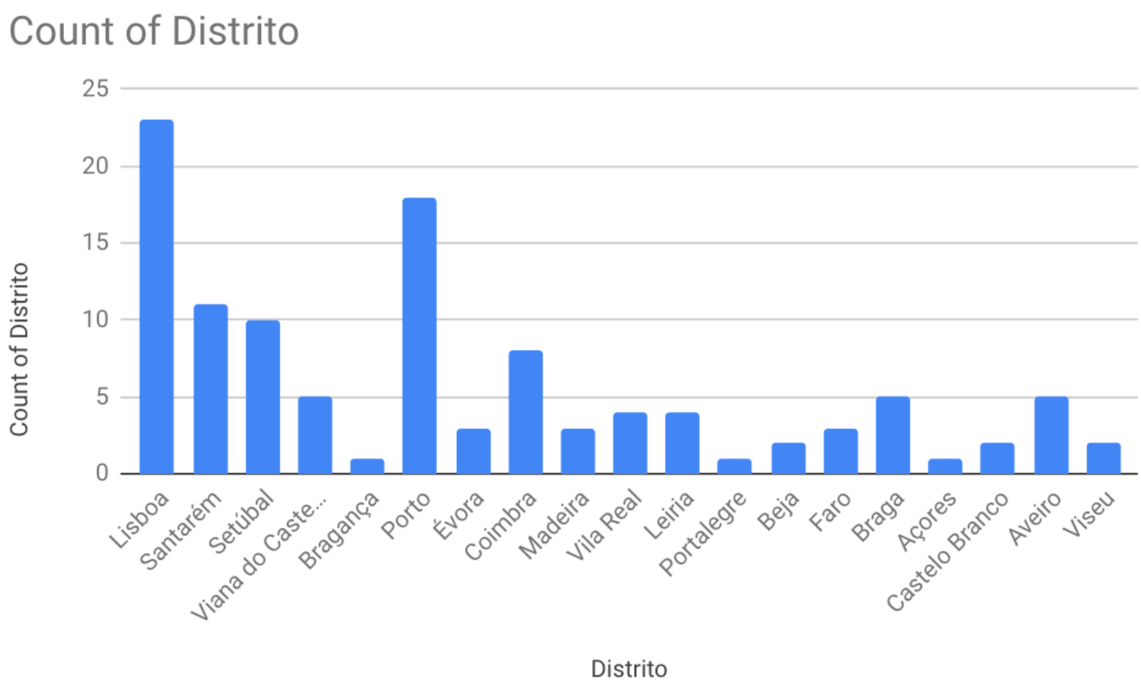
Zhang, G., Bernardini, F., Russell D., Gelfand, J., Lasota, J-P. Almannaei, A., Shaw, A., Lewis, F., Tomsick, J., Plotkin, R., Charles, P. , Miller-Jones, J., Maitra, D., Homan, J., Kobel, P., Perez, D. , Doran, R. , (submitted) *Two Bright Mini-outbursts end the 12-year Long Activity of the Black Hole Candidate Swift J1753.5-0127* ApJ.

Appendix I Digital Schools Self-Reflection Questionnaire

Distribution of Schools according the grade level



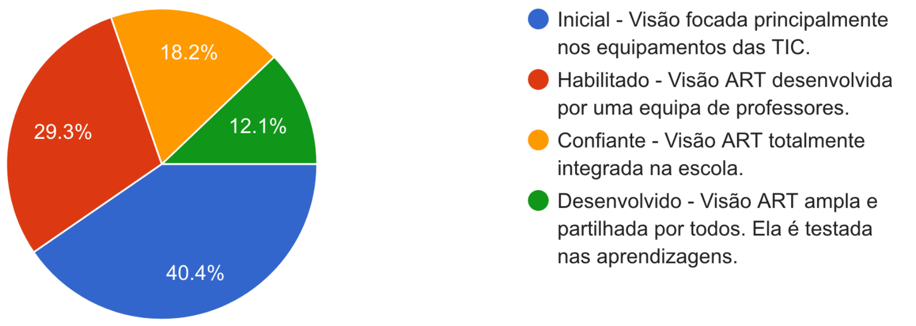
Distribution of Schools per District



Leadership and Planning

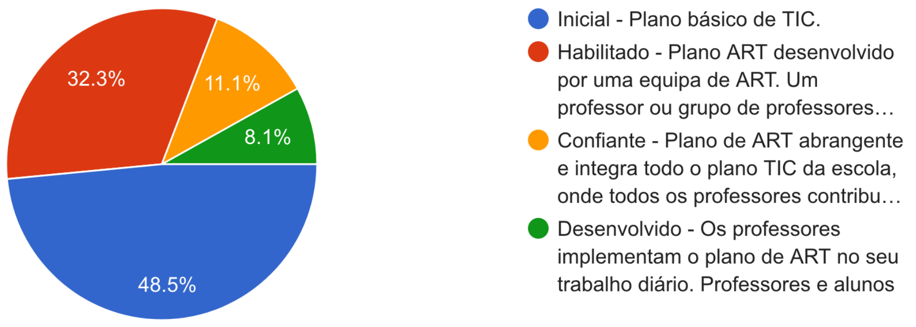
Visão

99 responses



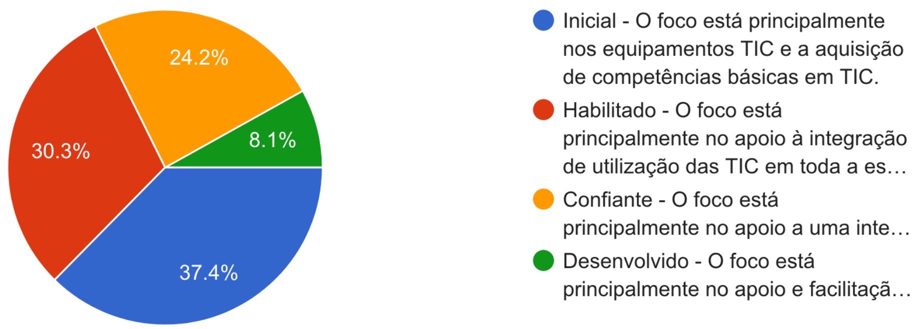
Plano

99 responses



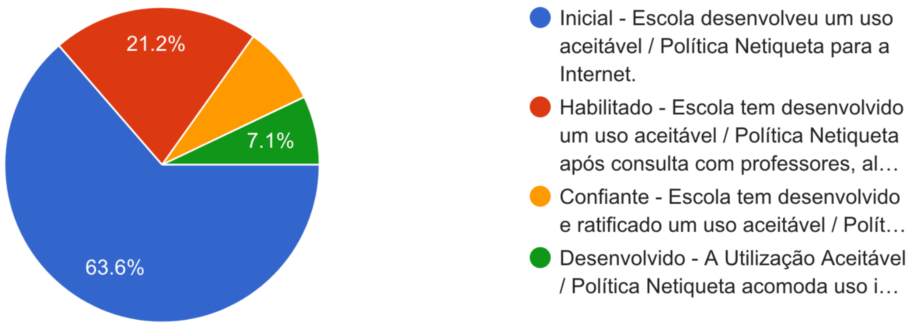
Integração

99 responses



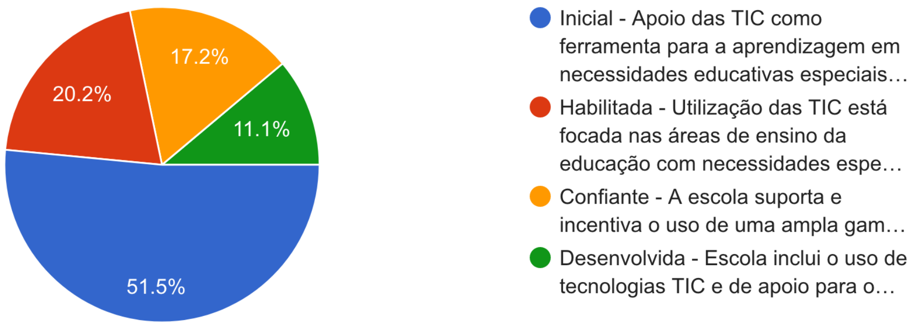
Utilização Aceitável / Política Netiqueta

99 responses



Necessidades Educativas Especiais

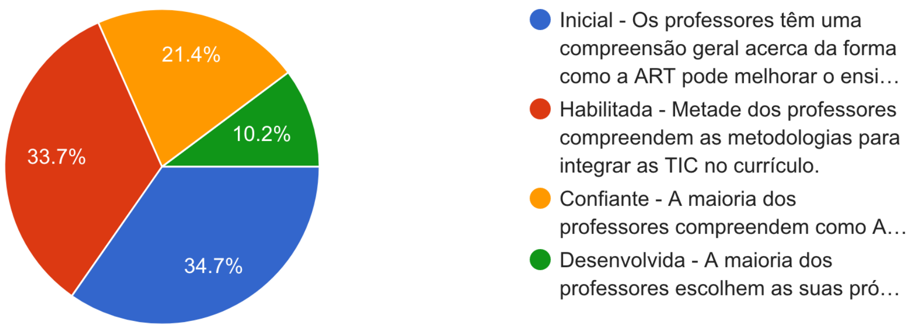
99 responses



ICT in the curricula

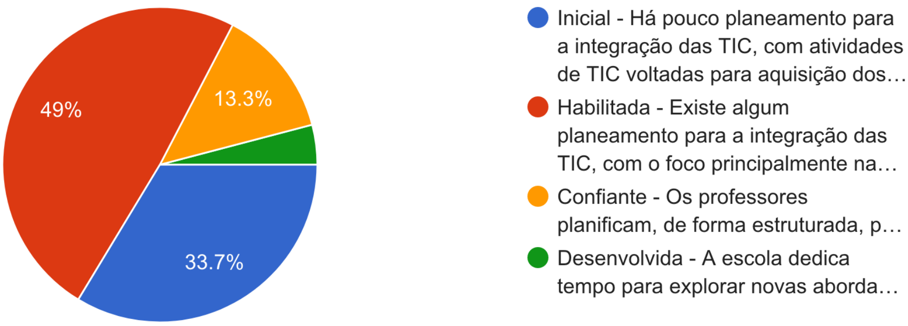
Nível de conhecimento do Professor

98 responses



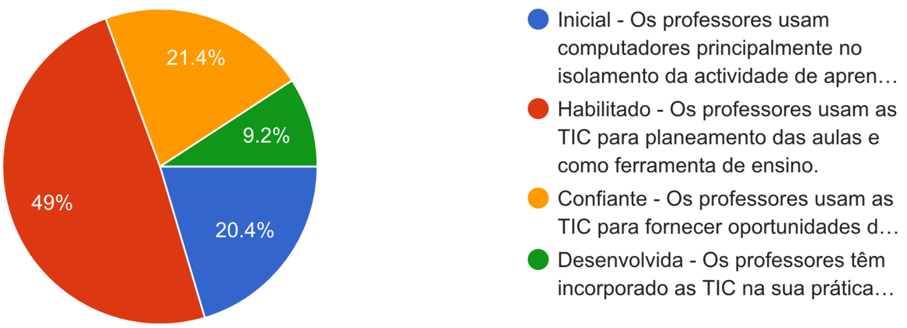
Planificação

98 responses



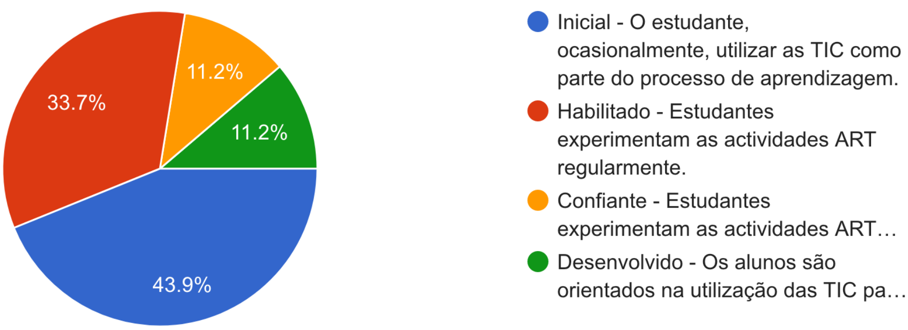
Utilização pelo Professor

98 responses



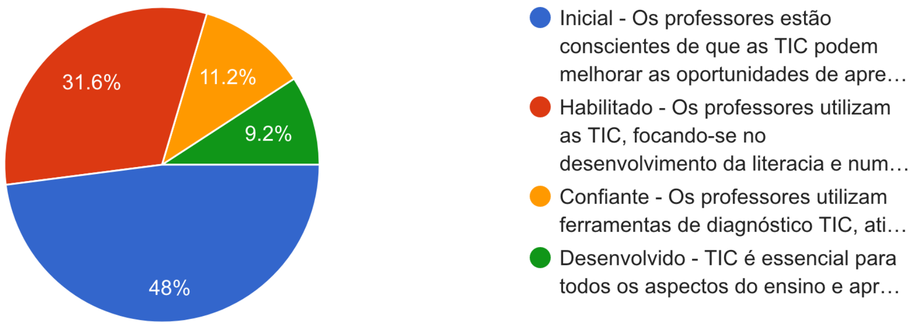
Experiência do Estudante

98 responses



Necessidades Educativas Especiais

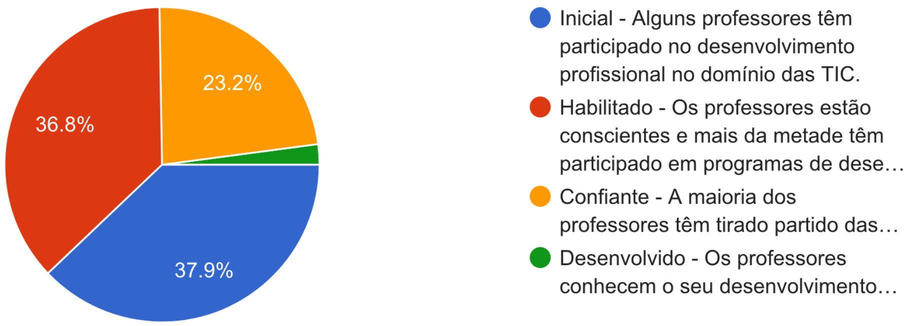
98 responses



Professional Development

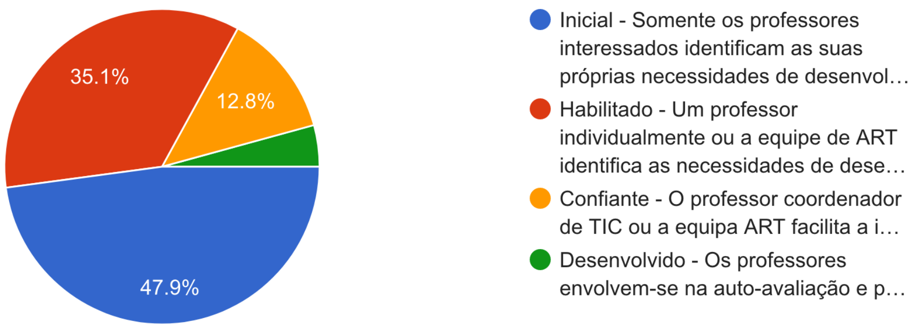
Consciência & Participação do Professor

95 responses



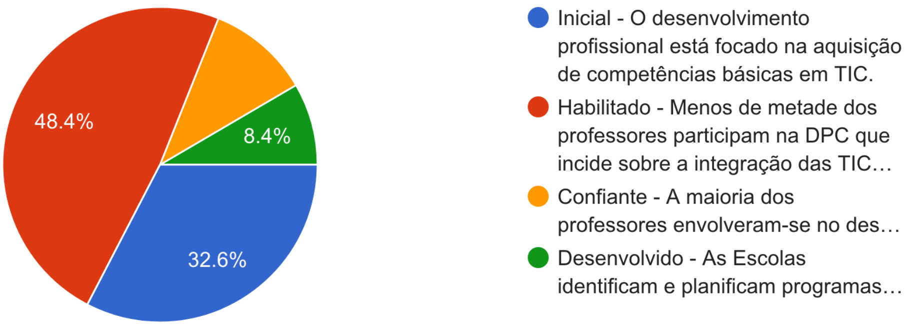
Planificação

94 responses



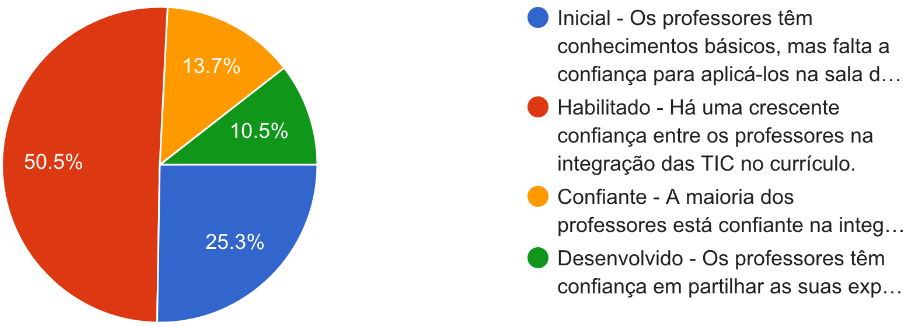
Foco

95 responses



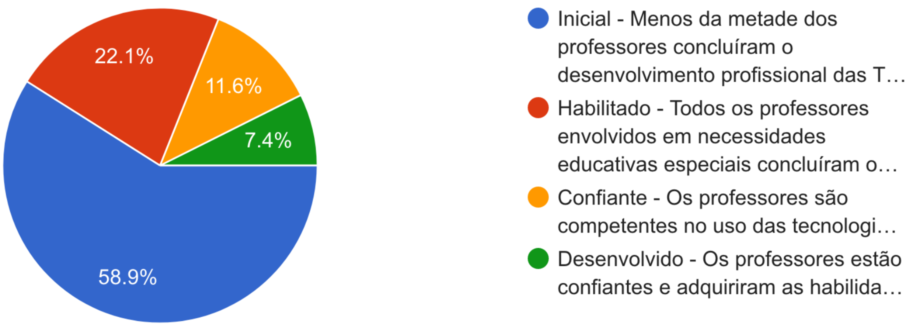
Confiança do Professor

95 responses



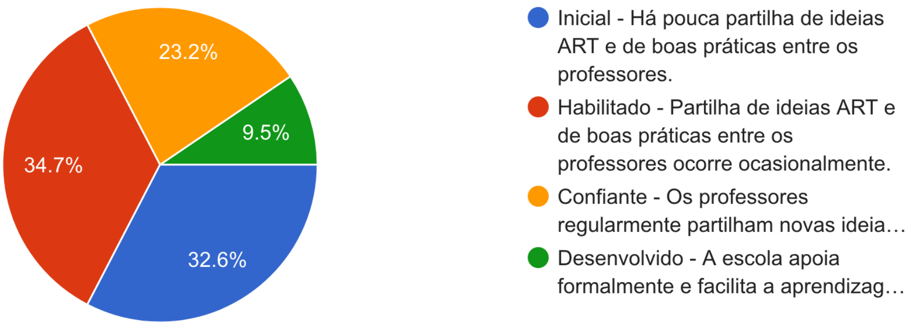
Necessidades Educativas Especiais

95 responses



Ensino Informal

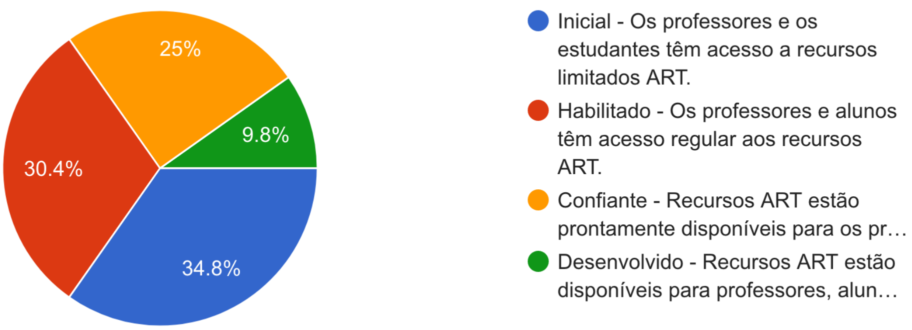
95 responses



TEL Culture

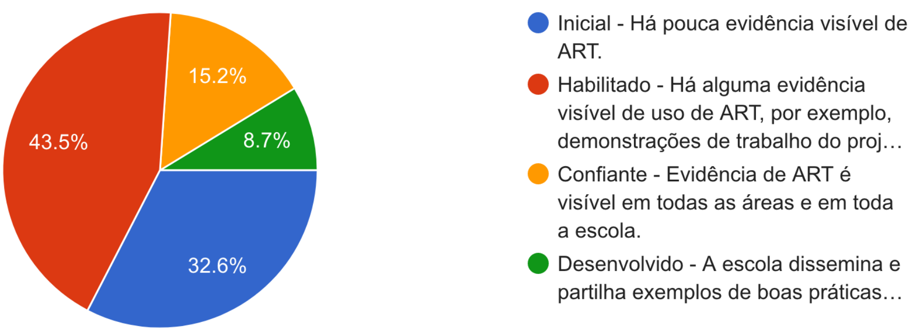
Acesso

92 responses



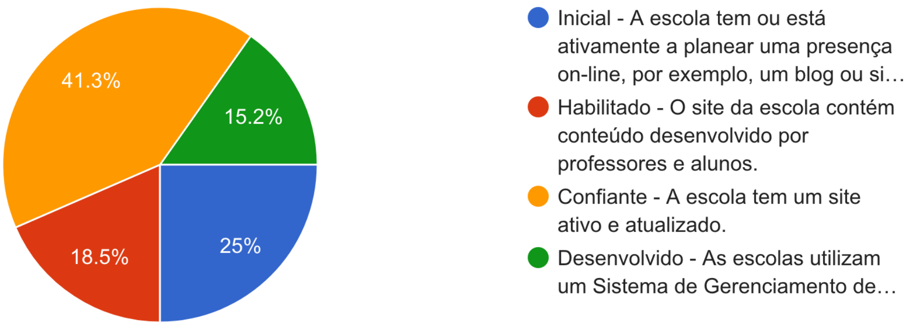
Evidência de Utilização

92 responses



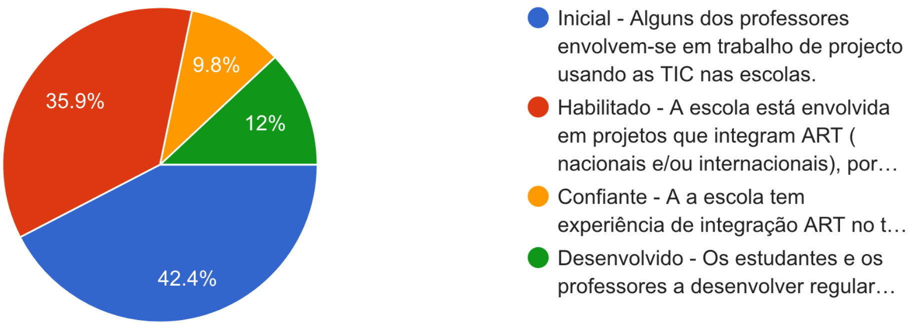
Página web / Presença Online

92 responses



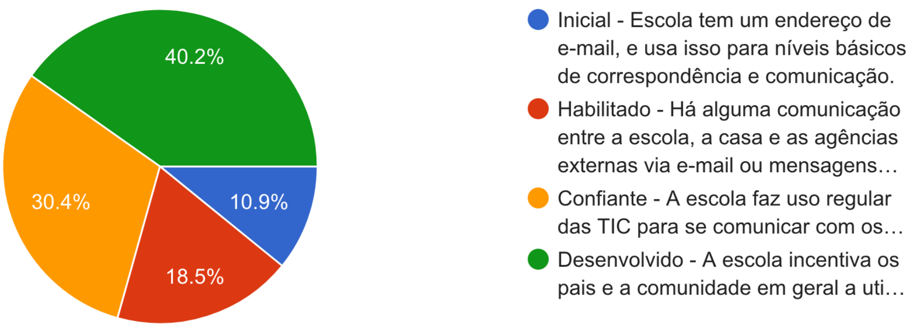
Projetos

92 responses



Organização e Comunicação

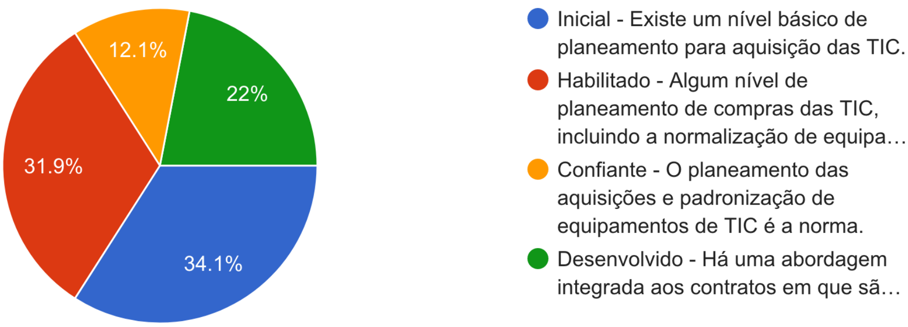
92 responses



TEL Resources and Infrastructure

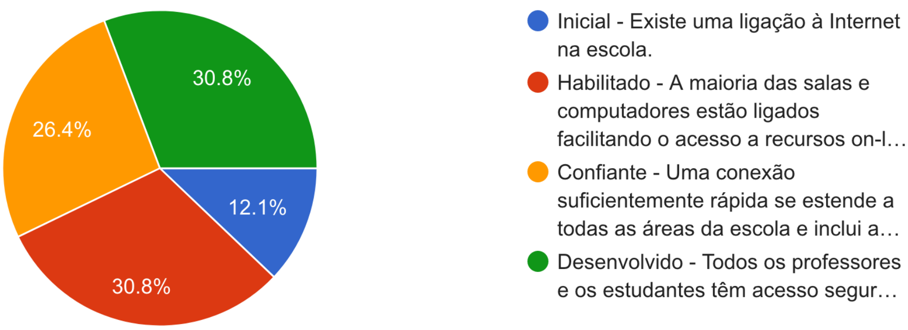
Planeamento para a aquisição de recursos

91 responses



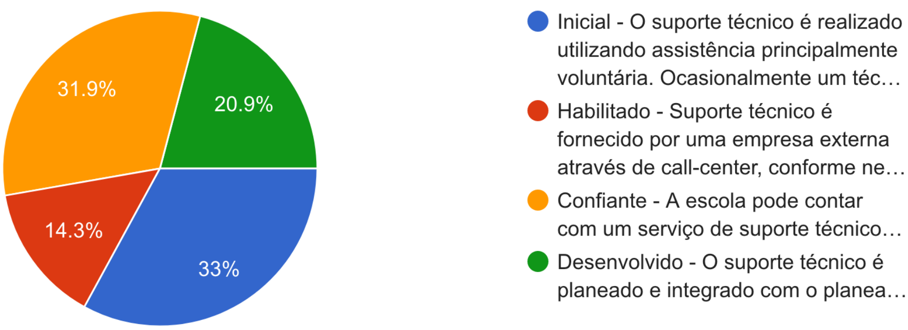
Disponibilidade de Acesso à Internet e Wi-Fi

91 responses



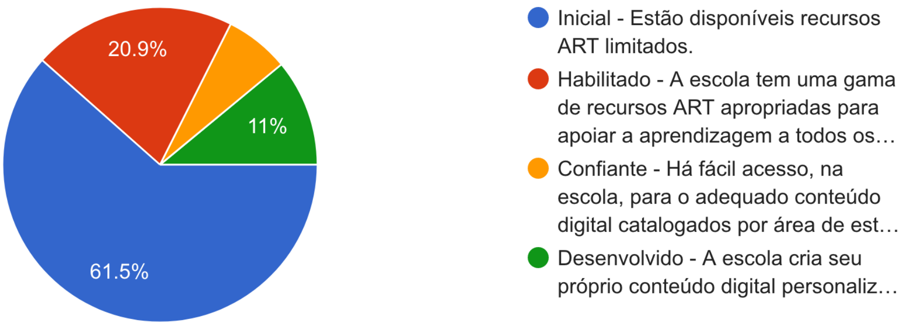
Suporte Técnico

91 responses



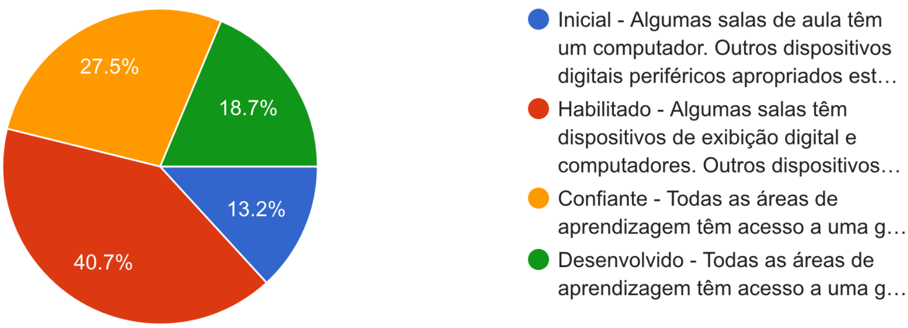
Conteúdo Digital

91 responses



Equipamento TIC

91 responses



FORMULÁRIO
AUTOAVALIAÇÃO DA APRENDIZAGEM REFORÇADA PELA TECNOLOGIA

Este formulário deve ser usado como uma ferramenta de autoavaliação para as escolas aferirem o seu desempenho com o uso de diferentes tipos de ferramentas tecnológicas no ensino seguindo os critérios do "Digital Schools of Europe". Se existir alguma questão/sugestão sobre isto, por favor contacte-nos em: info@escolas-digitais.org

Disclaimer

Privacidade versus funcionalidade

Esta primeira página da autoavaliação recolhe alguns dados sobre a escola e o professor que preenche este formulário. Nenhuma destas perguntas é de resposta obrigatória! O objetivo é permitir ao projeto fazer uma análise estatística e comparativa entre as escolas portuguesas e as escolas de outros países do "Digital Schools of Europe". Os dados fornecidos serão para uso exclusivo do projeto e não serão vendidos ou fornecidos a qualquer outra entidade. Note que devido a questões técnicas, a análise das respostas, cálculo dos resultados e os comentários e sugestões, são produzidos após a submissão do questionário, não sendo possível a sua apresentação imediata. Por este motivo é essencial o preenchimento do campo de Email se pretender receber uma cópia do formulário preenchido acompanhado da classificação, comentários e sugestões. Pode, se assim entender, manter o anonimato das respostas se escolher a opção "Apagar email após envio de resultados".

Dados identificativos

Email
Certifique-se da validade do email introduzido. Esta é a única forma de poder receber os resultados da autoavaliação. Se está registado no site Escolas Digitais, use aqui o mesmo email que utilizou no registo do site. Desta forma será possível guardar uma cópia das suas respostas na sua Área pessoal do site.

Privacidade e utilização dos dados fornecidos *
Leia com atenção o texto acima na secção "Privacidade e funcionalidade"
Escolha apenas uma opção.

- Li a secção "Privacidade e funcionalidade" e autorizo a utilização dos dados deste inquérito no âmbito descrito nessa secção.
- Desejo manter o anonimato. "Apagar email após envio de resultados"!

Escola

Nome do Professor
Se for um grupo de trabalho, basta introduzir o nome de um dos responsáveis.

Ciclo de estudos *
Check all that apply.

- 1º Ciclo
- 2º Ciclo
- 3º Ciclo
- Secundário

Distrito *
Escolha apenas uma opção.

- Aveiro
- Beja
- Braga
- Bragança

- Castelo Branco
- Coimbra
- Évora
- Faro
- Guarda
- Leiria
- Lisboa
- Portalegre
- Porto
- Santarém
- Setúbal
- Viana do Castelo
- Vila Real
- Viseu
- Açores
- Madeira

Por onde quer começar? (neste momento está na primeira página). *
Escolha apenas uma opção.

- 1. Liderança e Planificação Skip to question 8.
- 2. TIC no Currículo Skip to question 14.
- 3. Desenvolvimento Profissional Skip to question 20.
- 4. Cultura ART (Aprendizagem Reforçada pela Tecnologia) Skip to question 27.
- 5. ART Recursos & Infraestrutura Skip to question 33.
- Finalizar Stop filling out this form.

Liderança e Planificação

Esta área é sobre os planos que existem na escola para enriquecer o ensino usando a tecnologia. ART = "Aprendizagem Reforçada pela Tecnologia"

Visão *

Escolha apenas uma opção.

- Inicial - Visão focada principalmente nos equipamentos das TIC.
- Habilitado - Visão ART desenvolvida por uma equipa de professores.
- Confiante - Visão ART totalmente integrada na escola.
- Desenvolvido - Visão ART ampla e partilhada por todos. Ela é testada nas aprendizagens.

Plano *

Escolha apenas uma opção.

- Inicial - Plano básico de TIC.
- Habilitado - Plano ART desenvolvido por uma equipa de ART. Um professor ou grupo de professores assume(m) a liderança para a planificação das TIC na escola.

- Confiante - Plano de ART abrangente e integra todo o plano TIC da escola, onde todos os professores contribuem para a implementação do plano.
- Desenvolvido - Os professores implementam o plano de ART no seu trabalho diário. Professores e alunos

Integração *

Escolha apenas uma opção.

- Inicial - O foco está principalmente nos equipamentos TIC e a aquisição de competências básicas em TIC.
- Habilitado - O foco está principalmente no apoio à integração de utilização das TIC em toda a escola.
- Confiante - O foco está principalmente no apoio a uma integração mais abrangente das TIC e da exploração de abordagens novas e mais eficazes para a integração das TIC.
- Desenvolvido - O foco está principalmente no apoio e facilitação da aprendizagem personalizada e auto-dirigida.

Utilização Aceitável / Política Netiqueta *

Escolha apenas uma opção.

- Inicial - Escola desenvolveu um uso aceitável / Política Netiqueta para a Internet.
- Habilitado - Escola tem desenvolvido um uso aceitável / Política Netiqueta após consulta com professores, alunos, pais / encarregados de educação, e as partes interessadas.
- Confiante - Escola tem desenvolvido e ratificado um uso aceitável / Política Netiqueta para Internet e para uso das TIC após consultar os professores, alunos e pais. Todas as partes interessadas estão familiarizadas com o seu conteúdo e o plano é totalmente implementado.
- Desenvolvido - A Utilização Aceitável / Política Netiqueta acomoda uso inovador de novas tecnologias e facilita o desenvolvimento de uma abordagem ética e responsável para o uso dessas tecnologias.

Necessidades Educativas Especiais *

Escolha apenas uma opção.

- Inicial - Apoio das TIC como ferramenta para a aprendizagem em necessidades educativas especiais existe, mas é descoordenada.
- Habilitada - Utilização das TIC está focada nas áreas de ensino da educação com necessidades especiais.
- Confiante - A escola suporta e incentiva o uso de uma ampla gama de tecnologias TIC e de apoio em toda a escola para facilitar a inclusão de alunos com necessidades educativas especiais.
- Desenvolvida - Escola inclui o uso de tecnologias TIC e de apoio para o desenvolvimento de todos os Planos Educativo Individual (PEI) para os alunos com necessidades educativas especiais e usa TIC em todos os aspectos das necessidades educativas especiais.

TIC NO CURRÍCULO

Esta área é sobre como as TIC são usadas no ensino. TIC = Tecnologias de Informação e Comunicação NEE = Necessidades Educativas Especiais ART = Aprendizagem Reforçada pela Tecnologia

Nível de conhecimento do Professor *

Escolha apenas uma opção.

- Inicial - Os professores têm uma compreensão geral acerca da forma como a ART pode melhorar o ensino e aprendizagem.
- Habilitada - Metade dos professores compreendem as metodologias para integrar as TIC no currículo.
- Confiante - A maioria dos professores compreendem como ART pode ser usado no currículo para melhorar a aprendizagem dos alunos.
- Desenvolvida - A maioria dos professores escolhem as suas próprias metodologias para integração das TIC no currículo.

Planificação *

Escolha apenas uma opção.

- Inicial - Há pouco planeamento para a integração das TIC, com atividades de TIC voltadas para aquisição dos alunos de competências em TIC, por exemplo, processamento de texto.
- Habilitada - Existe algum planeamento para a integração das TIC, com o foco principalmente na preparação de professores, ensino de toda a turma, de grupo e de trabalho individual.
- Confiante - Os professores planificam, de forma estruturada, para a integração das TIC nas suas aulas e atividades dos alunos.
- Desenvolvida - A escola dedica tempo para explorar novas abordagens para usar ART para melhorar a aprendizagem dos alunos.

Utilização pelo Professor *

Escolha apenas uma opção.

- Inicial - Os professores usam computadores principalmente no isolamento da actividade de aprendizagem regularmente na sala de aula.
- Habilitado - Os professores usam as TIC para planeamento das aulas e como ferramenta de ensino.
- Confiante - Os professores usam as TIC para fornecer oportunidades de aprendizagem transversais, centralizadas no sujeito e aprendizagens de base construtivista.
- Desenvolvida - Os professores têm incorporado as TIC na sua prática para facilitar a aprendizagem e direcionada para o estudante. Há evidências consistentes de colaboração, atividades baseadas na descoberta e autênticas atividades ART em toda a escola.

Experiência do Estudante *
Escolha apenas uma opção.

- Inicial - O estudante, ocasionalmente, utilizar as TIC como parte do processo de aprendizagem.
- Habilitado - Estudantes experimentam as actividades ART regularmente.
- Confiante - Estudantes experimentam as actividades ART regularmente e utilizar as TIC para colaborar nas actividades curriculares, tanto dentro da escola e com outras escolas.
- Desenvolvido - Os alunos são orientados na utilização das TIC para apoiar e avaliar a sua aprendizagem, por exemplo, a criação de conteúdo digital e ePortfolios.

Necessidades Educativas Especiais *
Escolha apenas uma opção.

- Inicial - Os professores estão conscientes de que as TIC podem melhorar as oportunidades de aprendizagem dos alunos com necessidades educativas especiais.
- Habilitado - Os professores utilizam as TIC, focando-se no desenvolvimento da literacia e numeracia para os alunos com necessidades educativas especiais.
- Confiante - Os professores utilizam ferramentas de diagnóstico TIC, atividades NEE e recursos de TIC para abordar objetivos curriculares aos alunos com necessidades educativas especiais.
- Desenvolvido - TIC é essencial para todos os aspectos do ensino e aprendizagem das NEE, bem como no desenvolvimento dos PEI. Os recursos das TIC e actividades NEE são incorporadas em todos os níveis do planeamento escolar.

Para onde quer ir? (neste momento está na parte 2 - TIC no Currículo) *
Escolha apenas uma opção.

- Primeira página Start this form over.
- 1. Liderança e Planificação Skip to question 8.
- 3. Desenvolvimento Profissional Skip to question 20.
- 4. Cultura ART Skip to question 27.
- 5. ART Recursos & Infraestrutura Skip to question 33.
- Finalizar Stop filling out this form.

Desenvolvimento Profissional

Esta área é sobre a possibilidade de obter formação para os professores e técnicos da escola. TIC = Tecnologias da Informação e Comunicação NEE = Necessidades Educativas Especiais ART = "Aprendizagem Reforçada pela Tecnologia"
Consciência & Participação do Professor *
Escolha apenas uma opção.

- Inicial - Alguns professores têm participado no desenvolvimento profissional no domínio das TIC.

- Habilitado - Os professores estão conscientes e mais da metade têm participado em programas de desenvolvimento profissional nas TIC.
- Confiante - A maioria dos professores têm tirado partido das oportunidades de desenvolvimento profissional nas TIC no plano individual ou integral da escola.
- Desenvolvido - Os professores conhecem o seu desenvolvimento profissional através da participação ativa nas comunidades de prática de ensino e redes peer-to-peer.

Planificação
Escolha apenas uma opção.

- Inicial - Somente os professores interessados identificam as suas próprias necessidades de desenvolvimento profissional nas TIC.
- Habilitado - Um professor individualmente ou a equipe de ART identifica as necessidades de desenvolvimento profissional da escola em relação à integração das TIC.
- Confiante - O professor coordenador de TIC ou a equipa ART facilita a identificação de necessidades ART globais dos professores. Programa de DPC é desenvolvido.
- Desenvolvido - Os professores envolvem-se na auto-avaliação e prática reflexiva em curso de modo a progredir o programa da escola para a DPC.

Foco *
Escolha apenas uma opção.

- Inicial - O desenvolvimento profissional está focado na aquisição de competências básicas em TIC.
- Habilitado - Menos de metade dos professores participam na DPC que incide sobre a integração das TIC no currículo.
- Confiante - A maioria dos professores envolveram-se no desenvolvimento profissional relevante voltada para a integração das TIC no currículo.
- Desenvolvido - As Escolas identificam e planificam programas de desenvolvimento profissional para toda a escola com base em suas necessidades específicas.

Confiança do Professor *
Escolha apenas uma opção.

- Inicial - Os professores têm conhecimentos básicos, mas falta a confiança para aplicá-los na sala de aula.
- Habilitado - Há uma crescente confiança entre os professores na integração das TIC no currículo.
- Confiante - A maioria dos professores está confiante na integração das TIC no seu ensino diário.
- Desenvolvido - Os professores têm confiança em partilhar as suas experiências e práticas inovadoras dentro da sua própria escola e com outras escolas.

Necessidades Educativas Especiais *
Escolha apenas uma opção.

- Inicial - Menos da metade dos professores concluíram o desenvolvimento profissional das TIC & Necessidades Especiais.
- Habilitado - Todos os professores envolvidos em necessidades educativas especiais concluíram o desenvolvimento profissional em TIC e NEE.
- Confiante - Os professores são competentes no uso das tecnologias nas NEE e outras tecnologias para apoiar os alunos com necessidades educativas especiais.
- Desenvolvido - Os professores estão confiantes e adquiriram as habilidades para usar uma ampla gama de tecnologias para facilitar a inclusão de alunos com necessidades educativas especiais.

Ensino Informal *
Escolha apenas uma opção.

- Inicial - Há pouca partilha de ideias ART e de boas práticas entre os professores.
- Habilitado - Partilha de ideias ART e de boas práticas entre os professores ocorre ocasionalmente.
- Confiante - Os professores regularmente partilham novas ideias ART e boas práticas com os outros.
- Desenvolvido - A escola apoia formalmente e facilita a aprendizagem peer-to-peer em TIC.

Para onde quer ir? (neste momento está na parte 3 - Desenvolvimento Profissional) *
Escolha apenas uma opção.

- Primeira Página Start this form over.
- 1. Liderança e Planificação Skip to question 8.
- 2. TIC no Currículo Skip to question 14.
- 4. Cultura ART Skip to question 27.
- 5. ART Recursos & Infraestrutura Skip to question 33.
- Finalizar Stop filling out this form.

Cultura ART

Esta área é sobre a cultura da escola relativamente à utilização das TIC na educação. TIC = Tecnologias de Informação e Comunicação NEE = Necessidades Educativas Especiais ART = "Aprendizagem Reforçada pela Tecnologia"
Acesso *
Escolha apenas uma opção.

- Inicial - Os professores e os estudantes têm acesso a recursos limitados ART.
- Habilitado - Os professores e alunos têm acesso regular aos recursos ART.
- Confiante - Recursos ART estão prontamente disponíveis para os professores e alunos em toda a escola.
- Desenvolvido - Recursos ART estão disponíveis para professores, alunos e comunidade escolar fora do horário escolar.

Evidência de Utilização *
Escolha apenas uma opção.

- Inicial - Há pouca evidência visível de ART.
- Habilitado - Há alguma evidência visível de uso de ART, por exemplo, demonstrações de trabalho do projeto.
- Confiante - Evidência de ART é visível em todas as áreas e em toda a escola.
- Desenvolvido - A escola dissemina e partilha exemplos de boas práticas para além da sua própria comunidade escolar.

Página web / Presença Online *
Escolha apenas uma opção.

- Inicial - A escola tem ou está ativamente a planear uma presença on-line, por exemplo, um blog ou site básico.
- Habilitado - O site da escola contém conteúdo desenvolvido por professores e alunos.
- Confiante - A escola tem um site ativo e atualizado.
- Desenvolvido - As escolas utilizam um Sistema de Gerenciamento de Conteúdo (SGC) para criar um espaço comunicativo onde a comunidade escolar publica conteúdo e que está em conformidade com as diretrizes de acessibilidade.

Projetos *
Escolha apenas uma opção.

- Inicial - Alguns dos professores envolvem-se em trabalho de projecto usando as TIC nas escolas.
- Habilitado - A escola está envolvida em projetos que integram ART (nacionais e/ou internacionais), por exemplo eTwinning.
- Confiante - A a escola tem experiência de integração ART no trabalho interdisciplinar e em projetos de grande escala.
- Desenvolvido - Os estudantes e os professores a desenvolver regularmente projectos de pequena escala para a colaboração externa.

Organização e Comunicação *
Escolha apenas uma opção.

- Inicial - Escola tem um endereço de e-mail, e usa isso para níveis básicos de correspondência e comunicação.
- Habilitado - Há alguma comunicação entre a escola, a casa e as agências externas via e-mail ou mensagens de texto.
- Confiante - A escola faz uso regular das TIC para se comunicar com os professores, os pais e outras partes interessadas.
- Desenvolvido - A escola incentiva os pais e a comunidade em geral a utilizar as TIC para se comunicar com a escola. Professores, alunos e pais têm acesso online à documentação do aluno e calendário.

Para onde quer ir? (neste momento está na parte 4 - ART Cultura) *
Escolha apenas uma opção.

- Primeira Página Start this form over.
- 1. Liderança e Planificação Skip to question 8.
- 2. TIC no Currículo Skip to question 14.
- 3. Desenvolvimento Profissional Skip to question 20.
- 5. ART Recursos & Infraestrutura Skip to question 33.
- Finalizar Stop filling out this form.

ART Recursos & Infraestrutura

Esta área é sobre a infraestrutura das TIC na escola. TIC = Tecnologias de Informação e Comunicação NEE = Necessidades Educativas Especiais ART = "Aprendizagem Reforçada pela Tecnologia"
Planeamento para a aquisição de recursos *
Escolha apenas uma opção.

- Inicial - Existe um nível básico de planeamento para aquisição das TIC.
- Habilitado - Algum nível de planeamento de compras das TIC, incluindo a normalização de equipamentos de TIC.
- Confiante - O planeamento das aquisições e padronização de equipamentos de TIC é a norma.
- Desenvolvido - Há uma abordagem integrada aos contratos em que são considerados os custos totais de funcionamento de equipamento de TIC e da prestação de apoio técnico.

Disponibilidade de Acesso à Internet e Wi-Fi *
Escolha apenas uma opção.

- Inicial - Existe uma ligação à Internet na escola.
- Habilitado - A maioria das salas e computadores estão ligados facilitando o acesso a recursos on-line e da rede.
- Confiante - Uma conexão suficientemente rápida se estende a todas as áreas da escola e inclui acesso Wi-Fi.
- Desenvolvido - Todos os professores e os estudantes têm acesso seguro a recursos on-line e à documentação dentro da escola e remotamente.

Suporte Técnico *
Escolha apenas uma opção.

- Inicial - O suporte técnico é realizado utilizando assistência principalmente voluntária. Ocasionalmente um técnico é pago para realizar um trabalho urgente.
- Habilitado - Suporte técnico é fornecido por uma empresa externa através de call-center, conforme necessário. Nenhum contrato de suporte técnico está em vigor.
- Confiante - A escola pode contar com um serviço de suporte técnico organizado e consistente.

- Desenvolvido - O suporte técnico é planeado e integrado com o planeamento das aquisições das TIC, que considera mudanças e atualizações de sistemas e equipamentos de TIC numa base contínua.

Conteúdo Digital *
Escolha apenas uma opção.

- Inicial - Estão disponíveis recursos ART limitados.
- Habilitado - A escola tem uma gama de recursos ART apropriadas para apoiar a aprendizagem a todos os níveis.
- Confiante - Há fácil acesso, na escola, para o adequado conteúdo digital catalogados por área de estudo / currículo.
- Desenvolvido - A escola cria seu próprio conteúdo digital personalizado que é acessível a partir de casa e na escola.

Equipamento TIC *
Escolha apenas uma opção.

- Inicial - Algumas salas de aula têm um computador. Outros dispositivos digitais periféricos apropriados estão disponíveis como recursos partilhados.
- Habilitado - Algumas salas têm dispositivos de exibição digital e computadores. Outros dispositivos digitais periféricos são utilizados para as actividades ART.
- Confiante - Todas as áreas de aprendizagem têm acesso a uma gama de equipamentos de TIC, incluindo um dispositivo de exibição digital e vários partilhados, Wi-Fi disponível e dispositivos para melhorar o acesso do aluno aos recursos.
- Desenvolvido - Todas as áreas de aprendizagem têm acesso a uma gama de equipamentos de TIC. Prevê-se a utilização de dispositivos móveis dos alunos.

Appendix II BHIMS Online Course Assessment

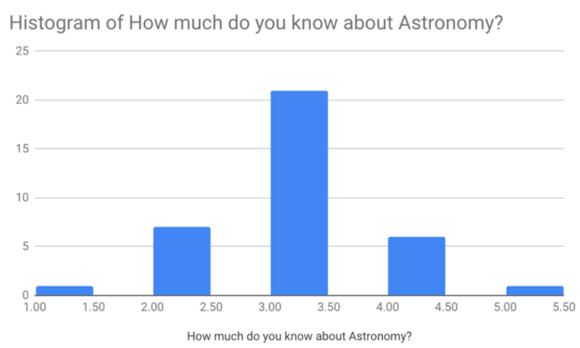
Module	Modules & Assignments	Evaluation criteria (passed)
Module 0 (week 1) **Overview of the objectives of the course, modules, tools and resources**	Presentation (live, video or picture of yourself and brief CV) Your vision for the participation in this course Pre-evaluation Questionnaire https://docs.google.com/forms/d/1GB6wbDyKDp2Ryrexl5xe3URESxFxaaeOkUl1ND_shNA/viewform Registering to the course page http://galileoteachers.academy/course/view.php?id=2 Registering to the online community http://portal.opendiscoveryspace.eu/community/bhims-black-holes-my-school-689404	Video or picture describing the participant is uploaded Brief CV Questionnaire Registration to the course page Registration to the ISE community BHIMS log book – Participants will be invited to keep a log book of all the activities performed during this course with their evaluation of the different components and meta-evaluation along the course.
Module 1 (week 2) **Introduction to Black Holes**	Include parts of this module in the Inquiry Scenario that will be built as one of the outcomes of this training. (To be delivered at a later stage in the course)	
Module 2 (week 3) **Some ICT Tools for Education**	Explore the following platforms: Go-lab and graasp http://www.golabz.eu/ http://graasp.eu/ Inspiring Science Education http://portal.opendiscoveryspace.eu Explore Salsa J http://portal.opendiscoveryspace.eu/sites/default/files/salsaj_201409.pdf Exploring Stellarium www.stellarium.org Exploring the Faulkes Telescope Archives and Educational Material http://www.faulkes-telescope.com/education/	Using the Go-lab portal and creation of an account at Graasp Finding resources in the Inspiring Science Education Community

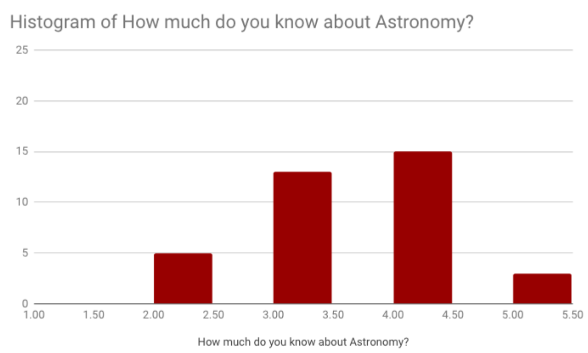
Module 3 (week 4) **Observing with Faulkes Telescope and Introduction to image processing**	Participants will have to prepare an observing session with Faulkes Telescope http://resources.faulkes-telescope.com/mod/resource/view.php?id=933 Participants will download images from the FT archives and process them with Salsa J	Know how to prepare an observing session and request images from Faulkes Telescope. Produce an astronomical colour image with Salsa J
Module 4 (week 5) **Inquiry and Inquiry learning spaces**	Participants will start the creation of their own Inquiry Scenario using either Graasp or ISE platform	Start the creation of their own Inquiry Scenario
Module 5 (week 6) **Photometry Techniques**	Participants will build a light curve of the selected object and introduce the instructions to perform this activity in the Inquiry Scenario for their students.	Know how to create a light curve and how to introduce the necessary tools in the Inquiry Scenarios
Module 6 Observing Stellar Black Holes (week 7) (week 8)	Create a light curve of a Black Hole Candidate	The light curve has to exhibit the characteristics of a binary system with a compact object as a companion
Module 7 Black Holes at the Centre of Galaxies (week 9) (week 10)	Reproduce the experiment performed by scientists to determine the mass of the black hole in the centre of our galaxy	Reproduction of the exercise and the determination of the mass of the black hole in the centre of our galaxy
Module 8 **Using and creating inquiry scenarios** **(week 11) (week 12) (week 13)**	Apply BHIMS ILS to a group of students Create a new ILS at Go-lab Portal: myILS Implement the module. Registering the experience in the log book. Create a new community and share myILS resources Prepare tools for case study	Plan of a module about Black Holes using the inquiry approach and resources presented.
Module 9 (week 14) Impact on	Impact on Teachers Practice Presentation of the log of all performed	Report. Presentation of a summary

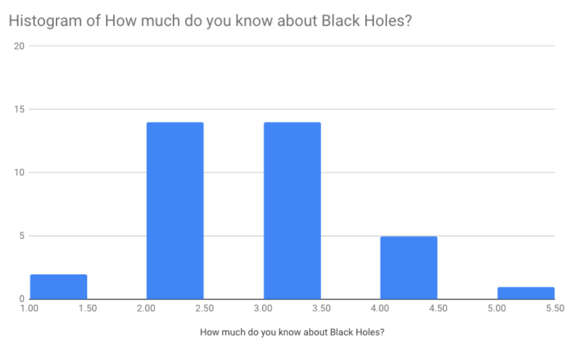
Teacher's practice	activities Identifying opportunities and barriers.	
Module 10 (week 15) **Impact on student's participation**	Impact on students' satisfaction and learning. Collecting data.	Presentation of an evaluation of the impact on students.
Week 16 **Reports, meta evaluation and case studies presentation**	Summarizing and reporting data. Deliver a full report of the activities, self-evaluation and BHIMS evaluation	Data is analysed and reported

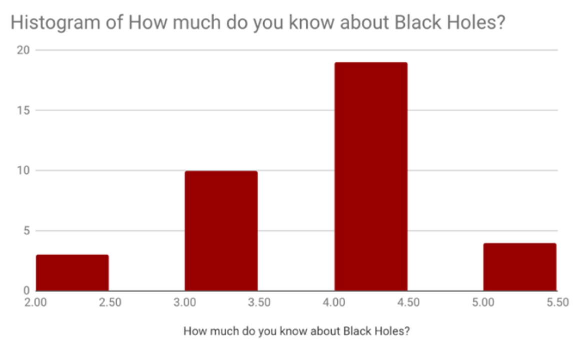
Appendix III Summary of the Answers to the Black Holes in my School Study (Pre and Post Questionnaire)

Summary of Answers Black Holes in My School

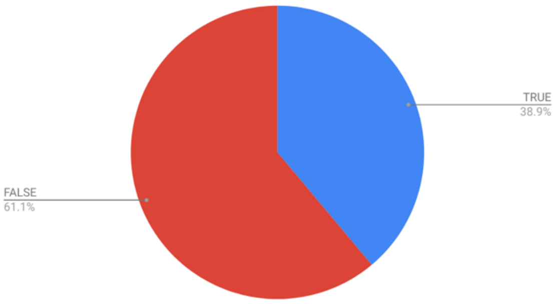




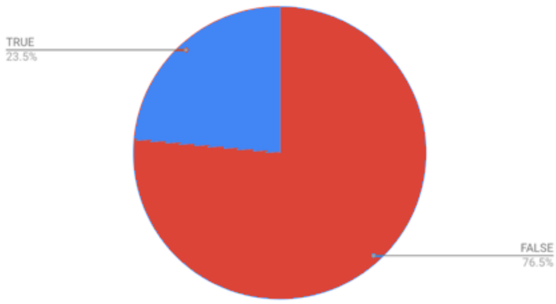




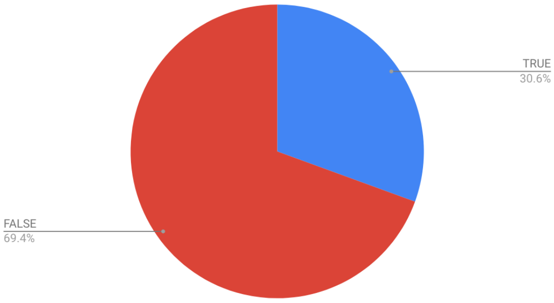
Count of All stars can become black holes



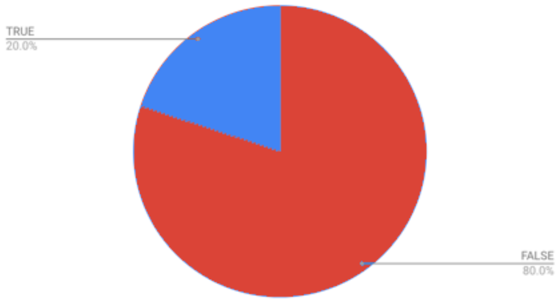
Count of All stars can become black holes



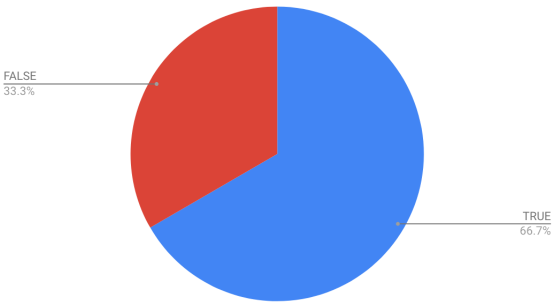
Count of The Sun one day will become a black hole



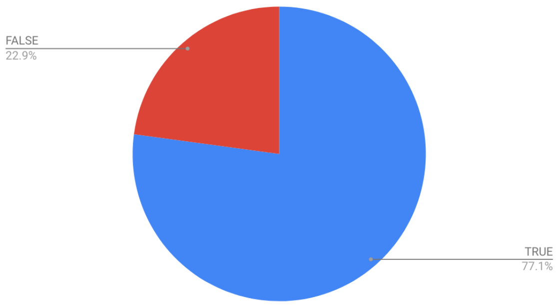
Count of The Sun one day will become a black hole



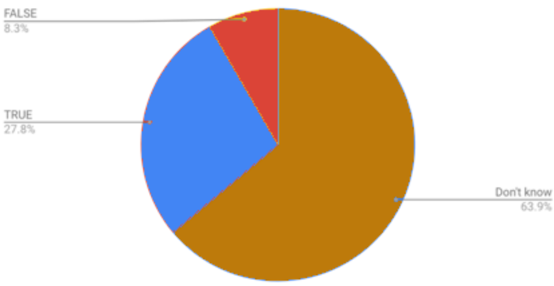
Count of We can't see a black hole directly



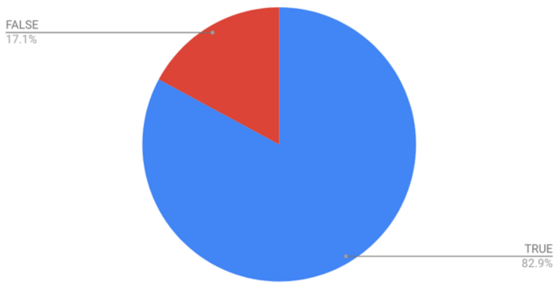
Count of We can't see a black hole directly



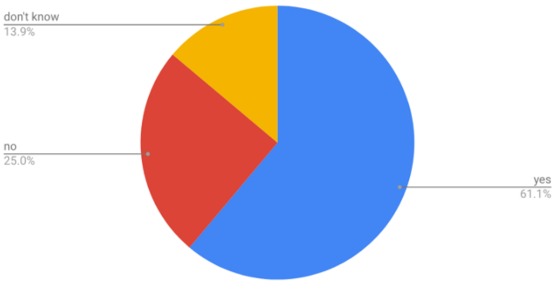
Count of Scientists believe that there is a black hole with a mass a million times larger than our Sun's in the center of our...



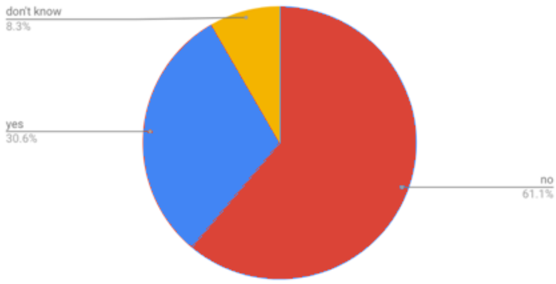
Count of Scientists believe that there is a black hole with a mass a million times larger than our Sun's in the center of our...



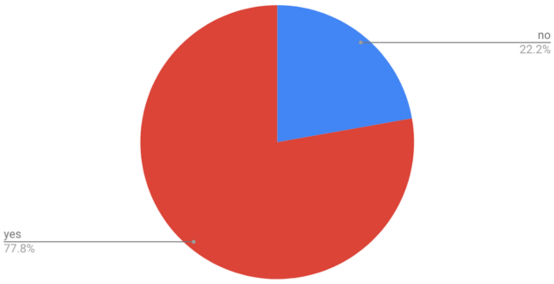
Count of Do you think a black hole can be compared to a vacuum cleaner?



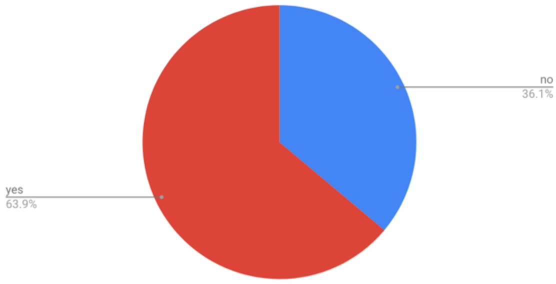
Count of Do you think a black hole can be compared to a vacuum cleaner?



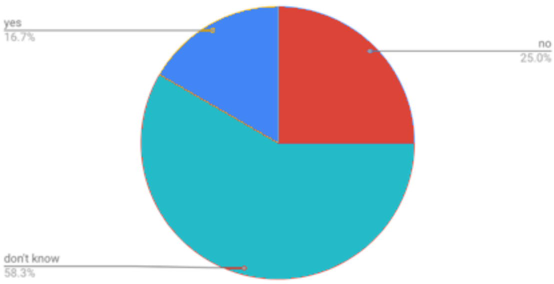
Count of If the Sun became a black hole, would the Earth disappear?



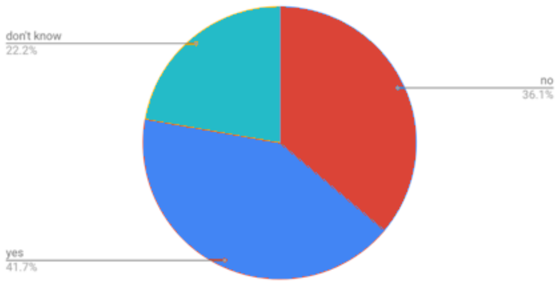
Count of If the Sun became a black hole, would the Earth disappear?



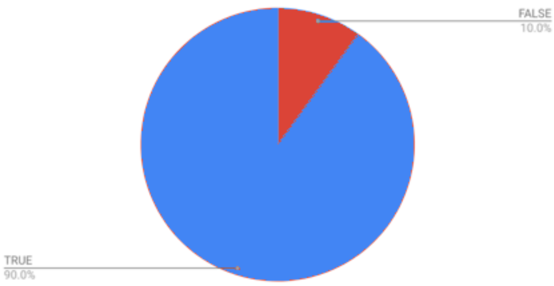
Count of Can our Universe be compared to a black hole or a white hole?



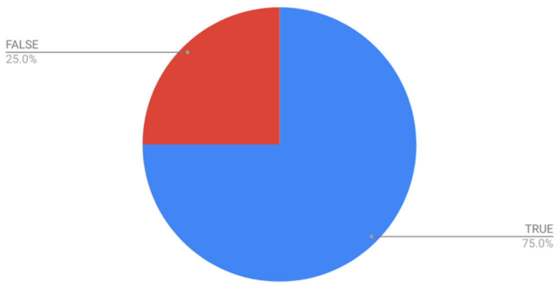
Count of Can our Universe be compared to a black hole or a white hole?



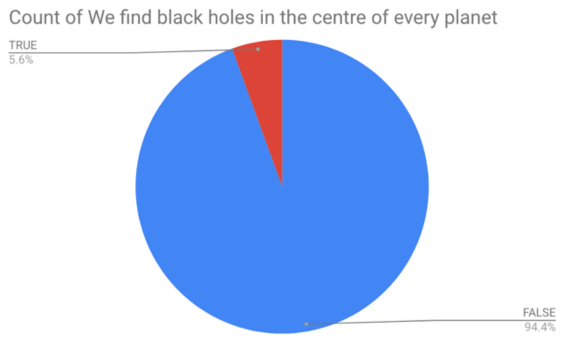
Count of Scientists believe that black holes can form at the end of the lifetime of a star

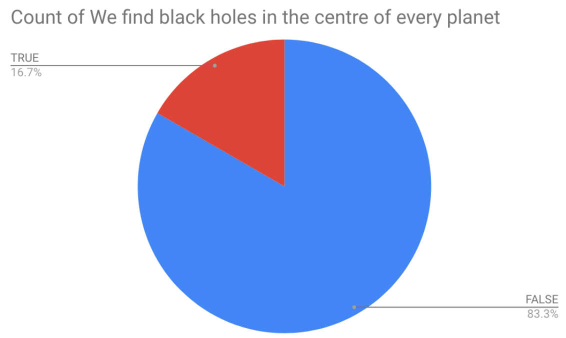


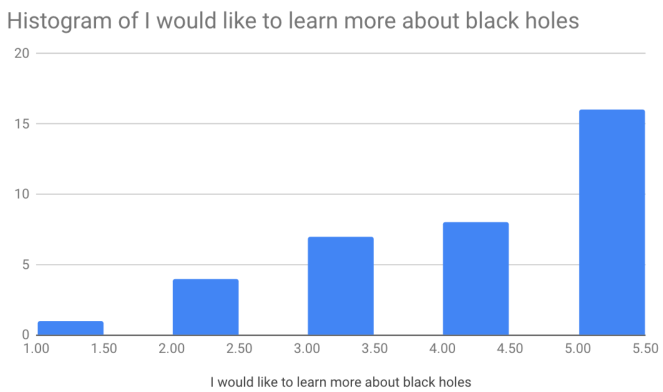
Count of Scientists believe that black holes can form at the end of the lifetime of some stars

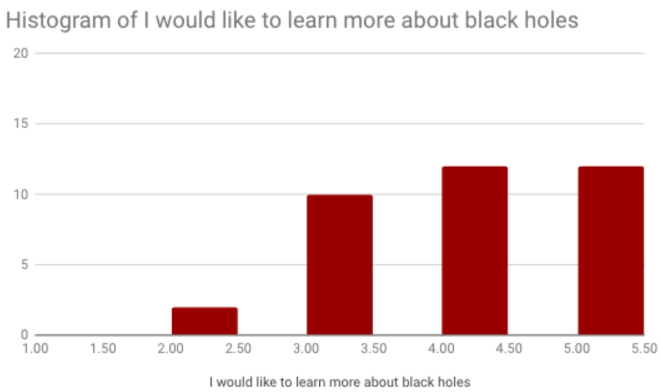


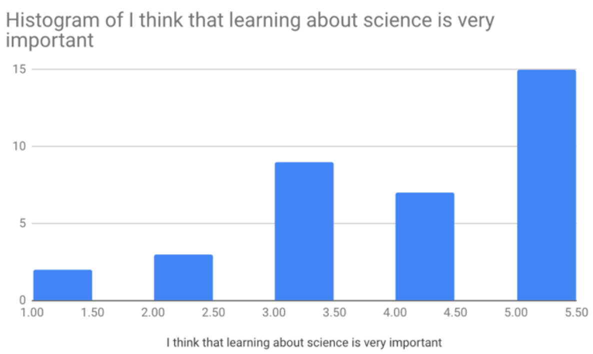
Summary of the Answers to the Black Holes in my School Study (Pre and Post Questionnaire)

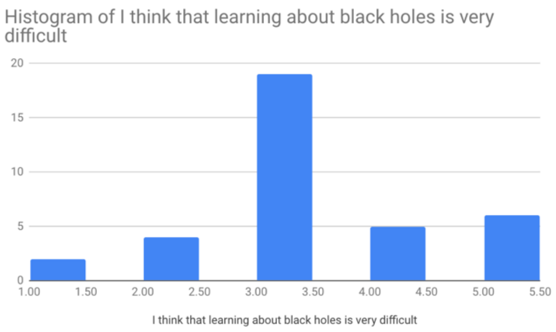


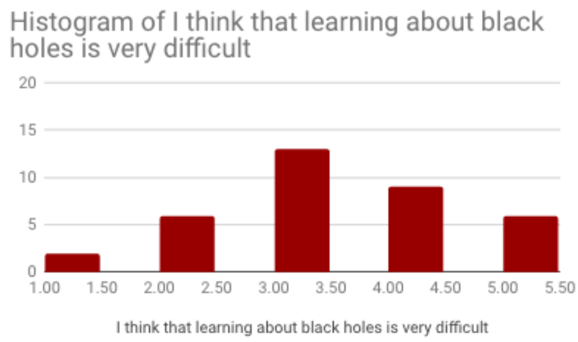


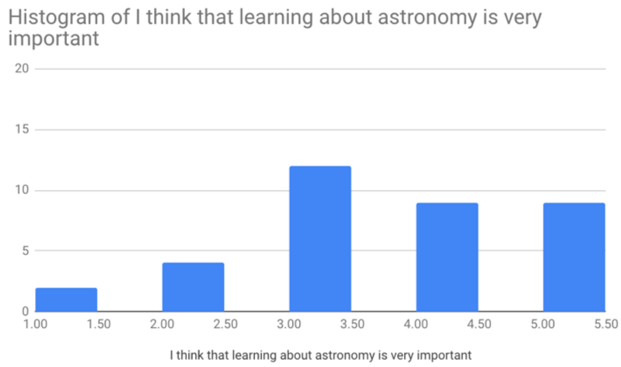


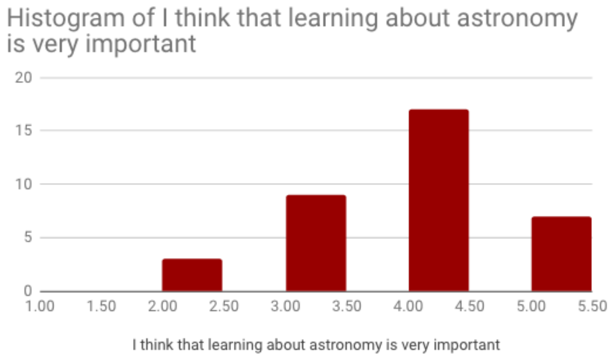


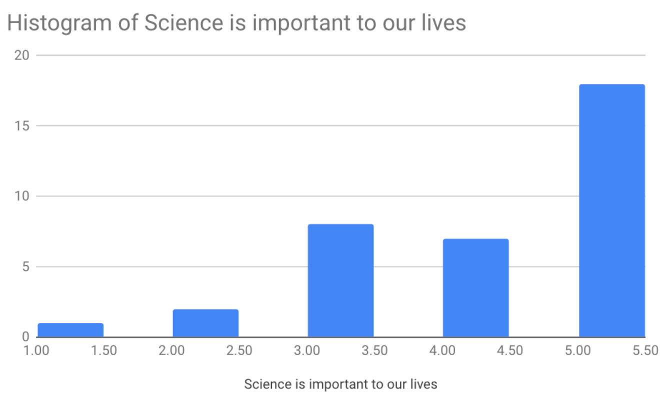


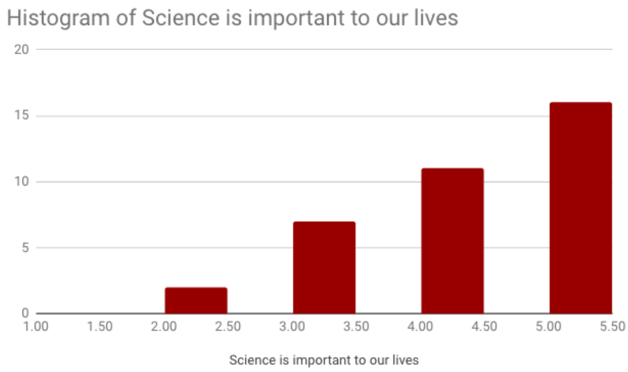

Histogram of I think that learning about black holes is very difficult
20
15
10
5
0
1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50
I think that learning about black holes is very difficult


Histogram of I think that learning about black holes is very difficult
20
15
10
5
0
1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50
I think that learning about black holes is very difficult


Histogram of I think that learning about astronomy is very important
20
15
10
5
0
1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50
I think that learning about astronomy is very important

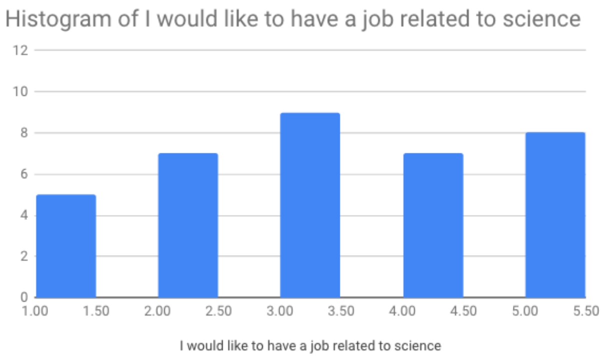

Histogram of I think that learning about astronomy is very important
20
15
10
5
0
1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50
I think that learning about astronomy is very important

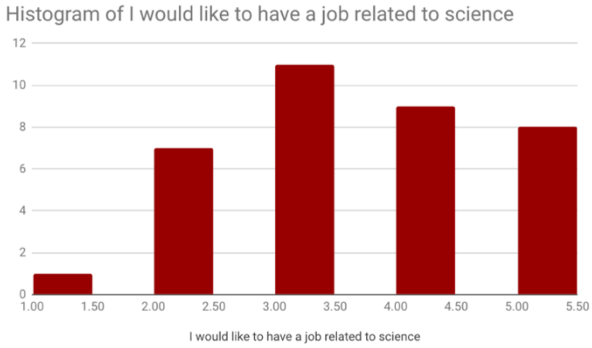

Histogram of Science is important to our lives
20
15
10
5
0
1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50
Science is important to our lives

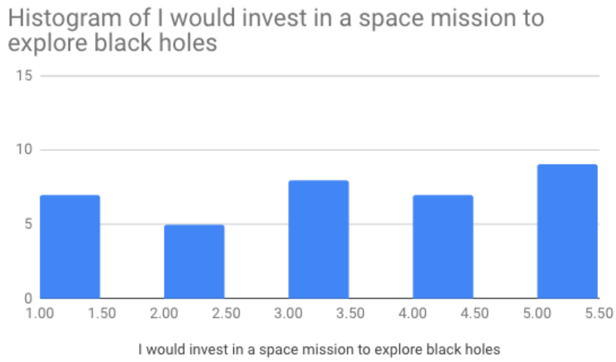

Histogram of Science is important to our lives
20
15
10
5
0
1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50
Science is important to our lives

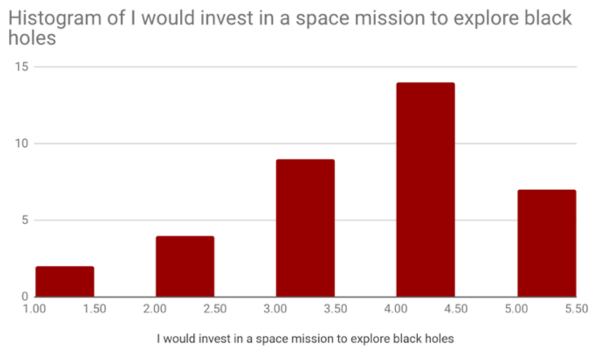

Histogram of I like to learn science
I like to learn science

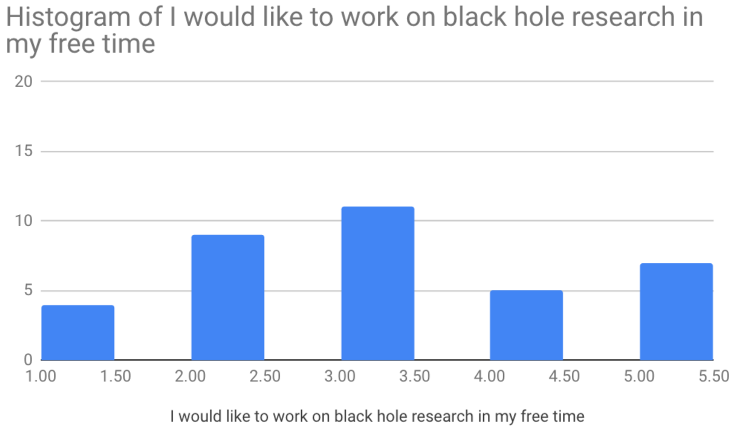

Histogram of I like to learn science
I like to learn science

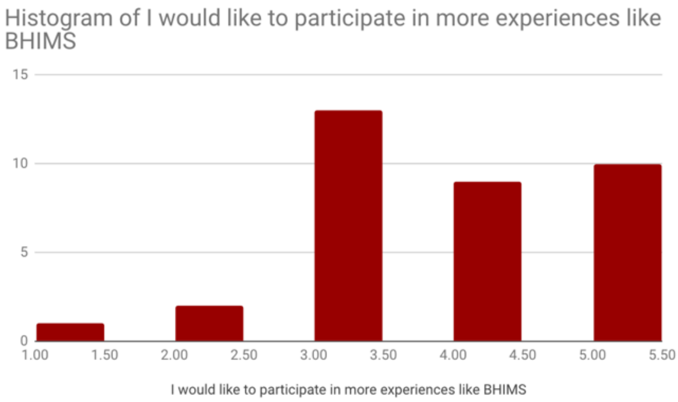

Histogram of I would like to have a job related to science
I would like to have a job related to science


Histogram of I would like to have a job related to science
I would like to have a job related to science


Histogram of I would invest in a space mission to explore black holes
I would invest in a space mission to explore black holes

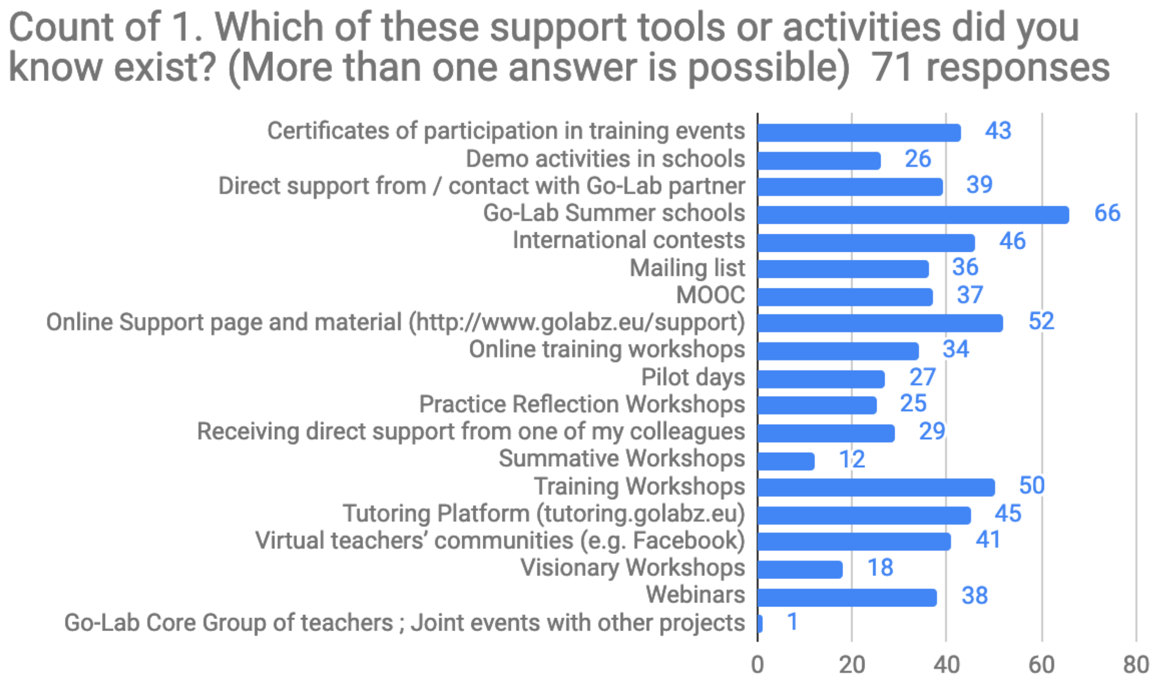

Histogram of I would invest in a space mission to explore black holes
I would invest in a space mission to explore black holes

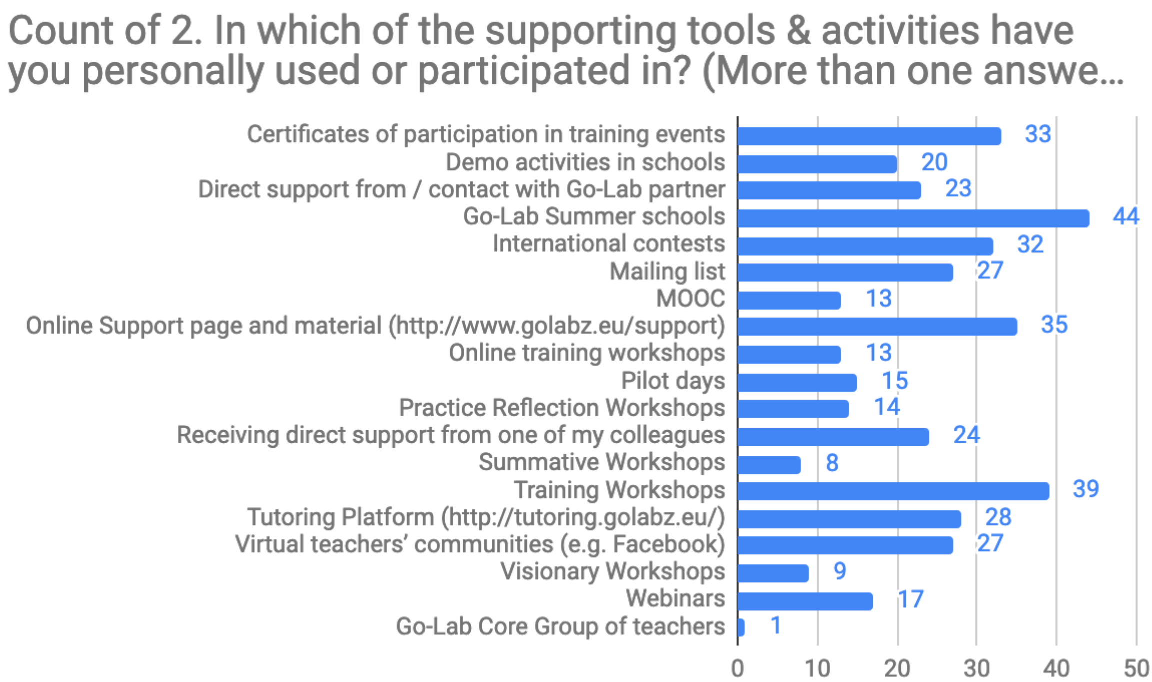

Histogram of I would like to work on black hole research in my free time
20
15
10
5
0
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
I would like to work on black hole research in my free time


Histogram of I would like to participate in more experiences like BHIMS
15
10
5
0
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
I would like to participate in more experiences like BHIMS

Appendix IV Go-Lab Teacher's Community Support Framework

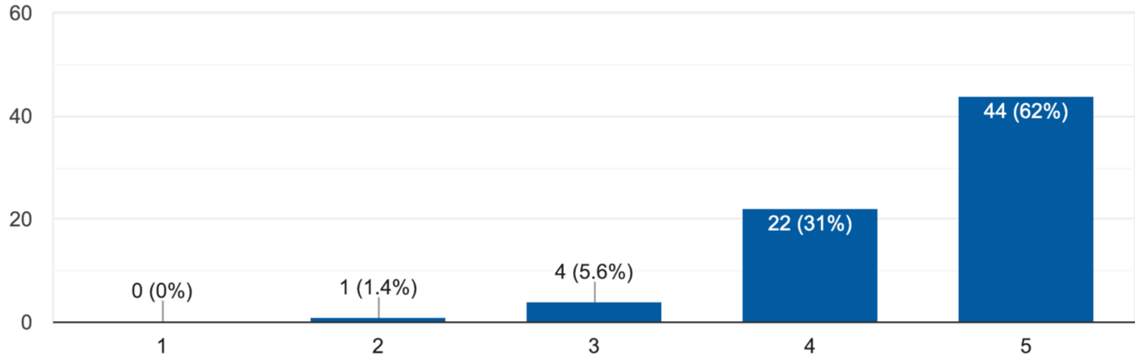
(71 responses)





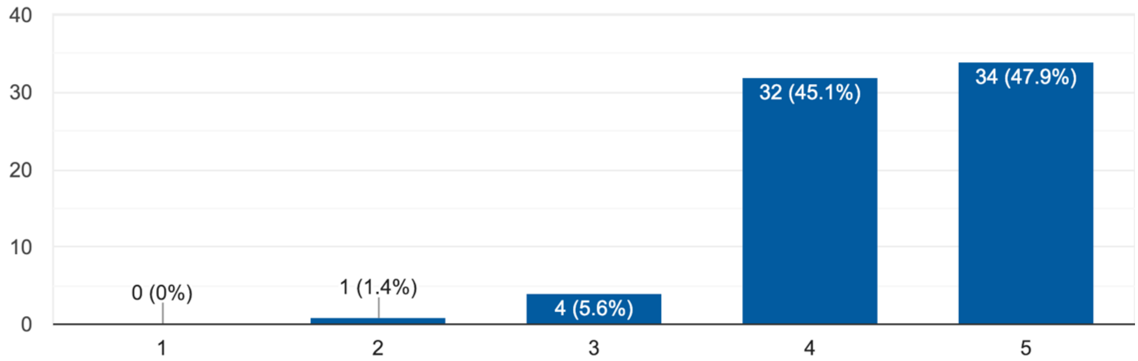
3. Do you consider the overall support in Go-Lab offered and received as adequate?

71 responses



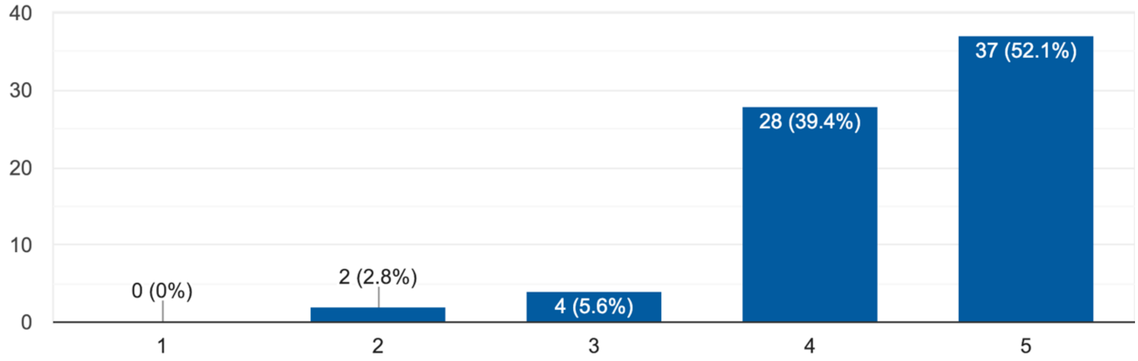
4. Do you consider the overall physical / on-site support in Go-Lab offered and received as suitable?

71 responses

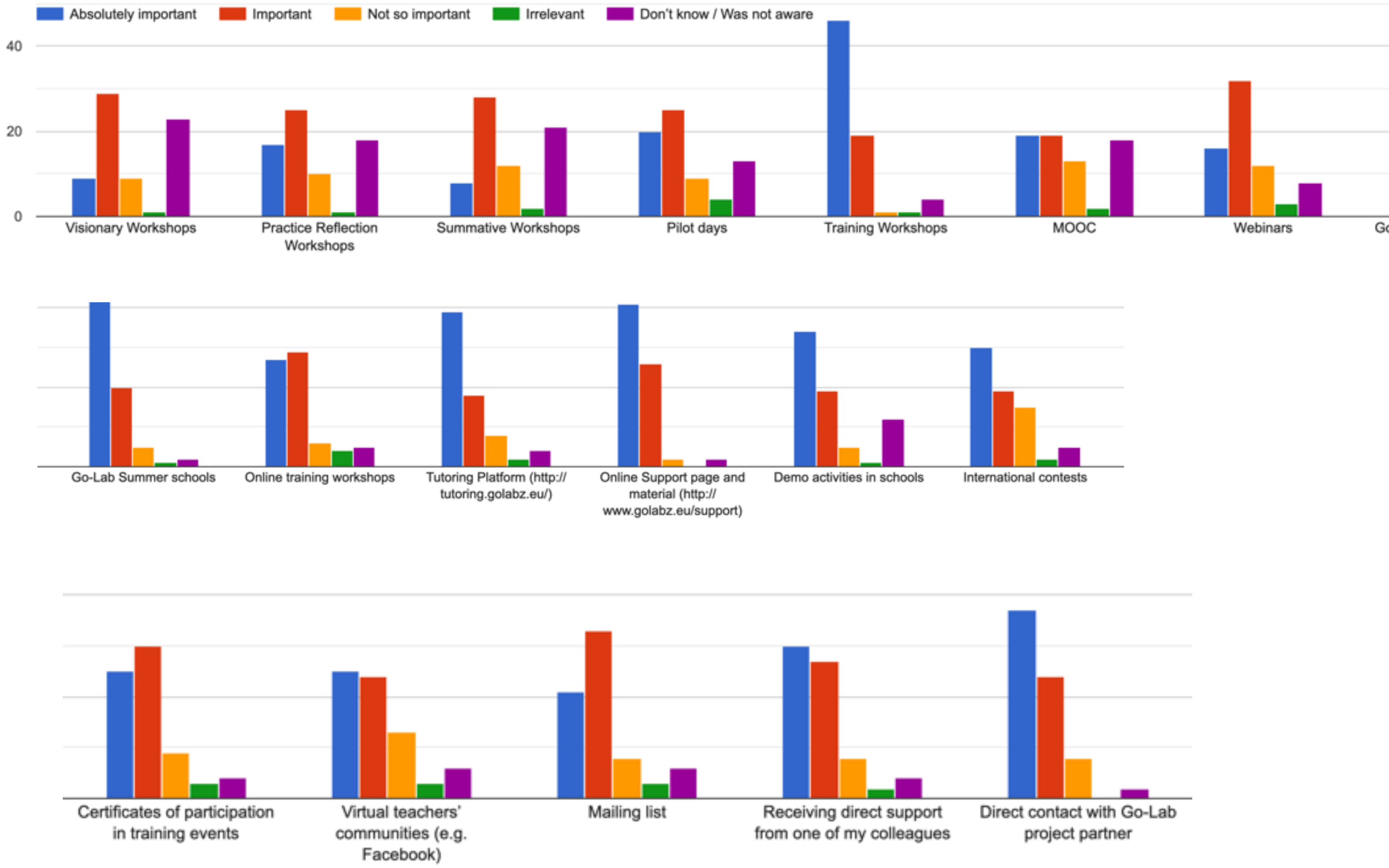


5. Do you consider the overall virtual / online support in Go-Lab offered and received as suitable?

71 responses

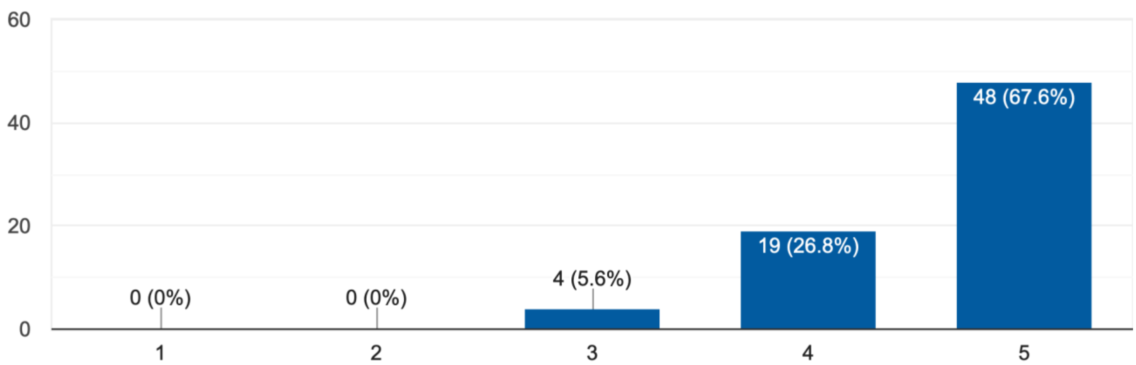


6. Which of the support tools & activities do you consider to be the most important for your participation in Go-Lab?



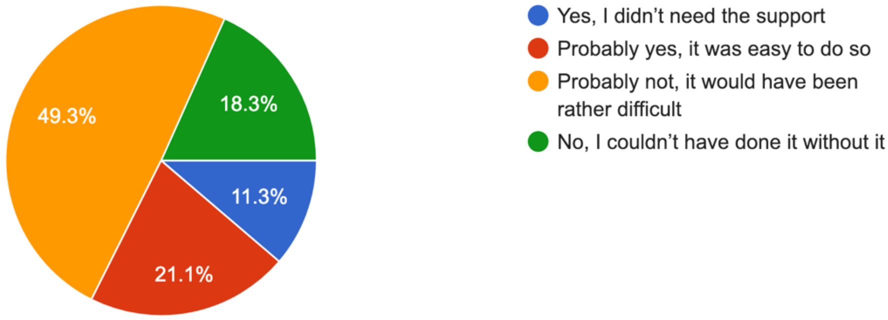
7. How would you rate the overall usefulness of the supporting tools & activities in understanding the principles of Inquiry Based Science Education (IBSE)?(workshop)

71 responses



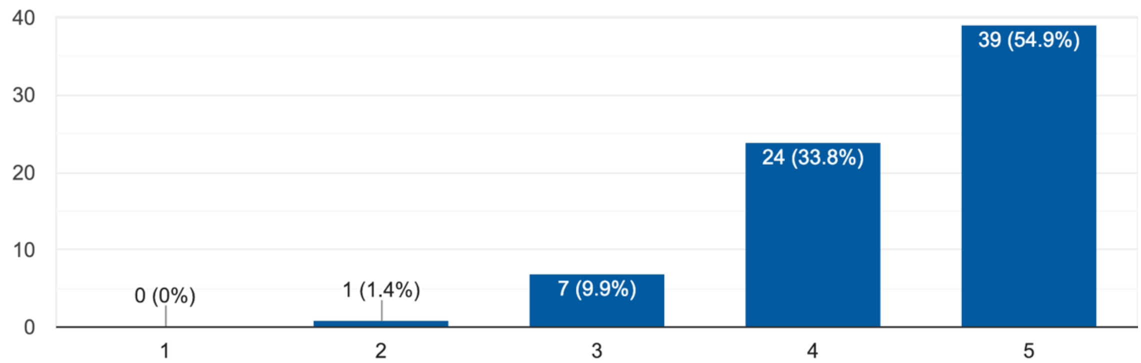
8. Would you have created a ILS without the support tools & activities offered in Go-Lab?

71 responses



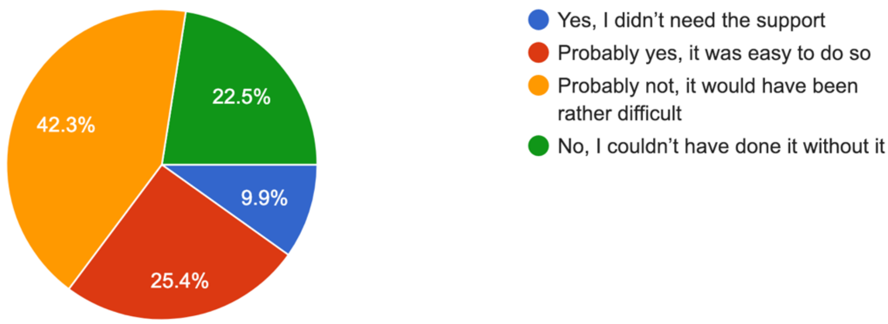
9. How would you rate the overall usefulness of the supporting tools & activities for the creation of a ILS on the Graasp platform?

71 responses



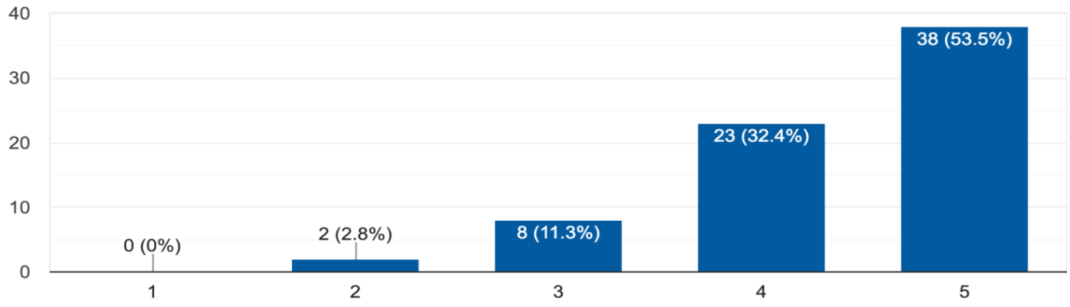
10. Would you have implemented a ILS without the support tools & activities offered in Go-Lab?

71 responses

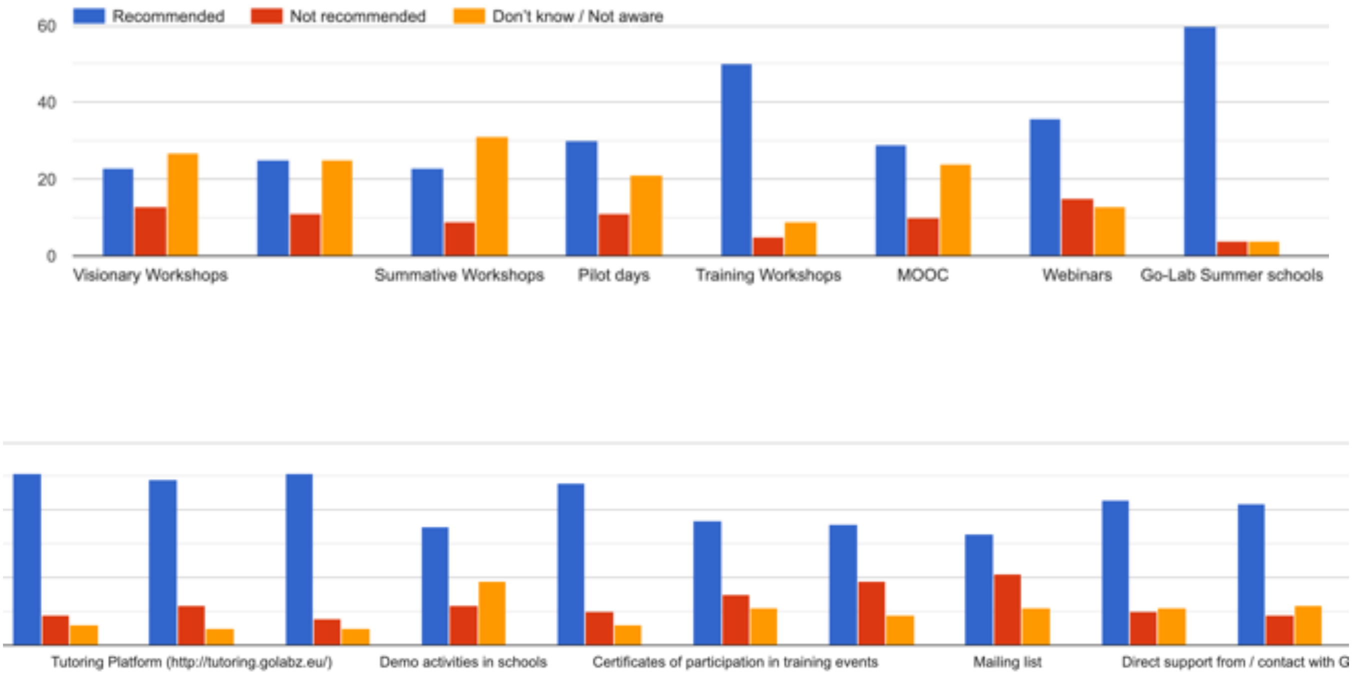


11. How would you rate the overall usefulness of the supporting tools & activities for the implementation...an ILS within an educational setting?

71 responses

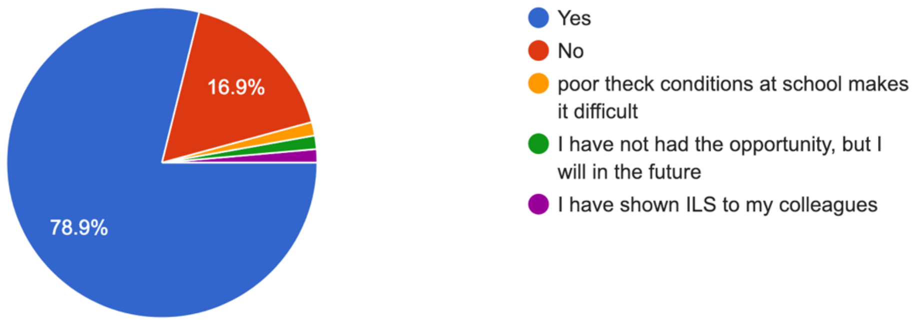


13. Have you recommended any of the supporting tools & activities to any of your colleagues?

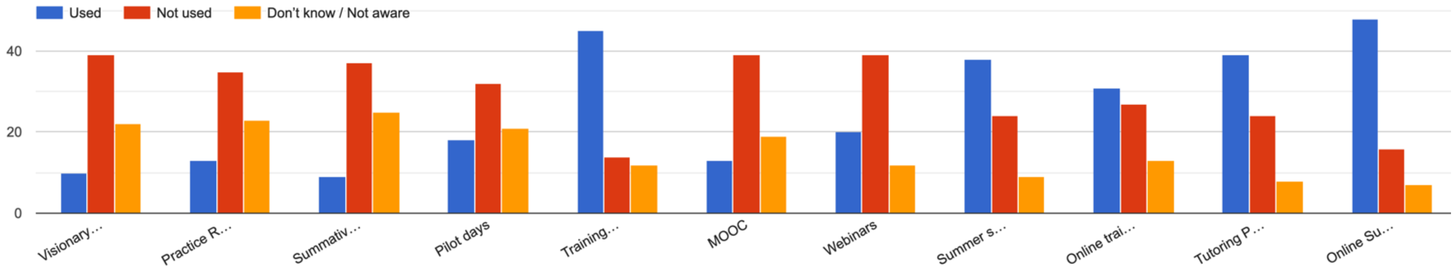


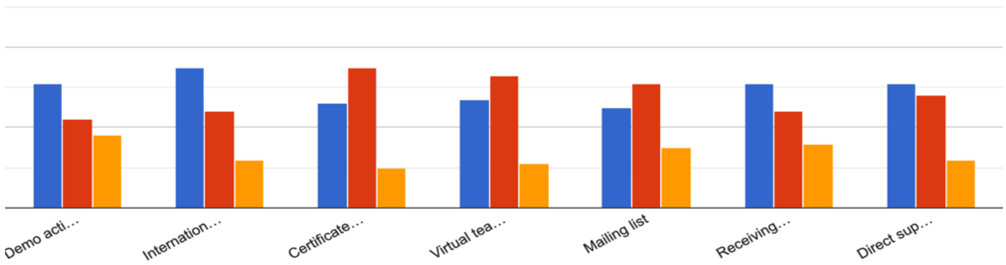
14. Have you encouraged, engaged or trained any of your colleagues in the use of Go-Lab?

71 responses



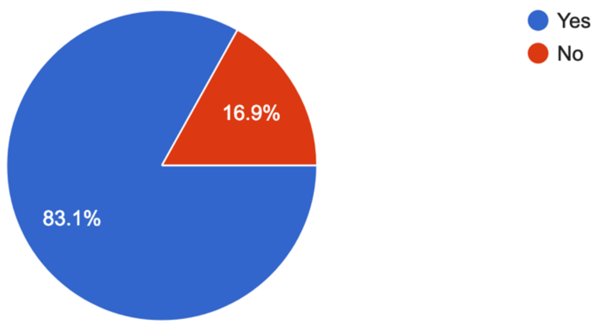
15. Which of the support tools & activities have you used in the engaging, promoting or training colleagues in the use Go-Lab?





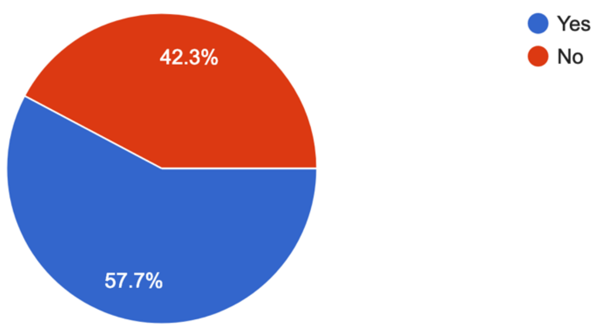
16. Are you in regular contact with other Go-Lab teachers outside of your school (e.g. through email, Facebook, physical meetings, etc.)?

71 responses



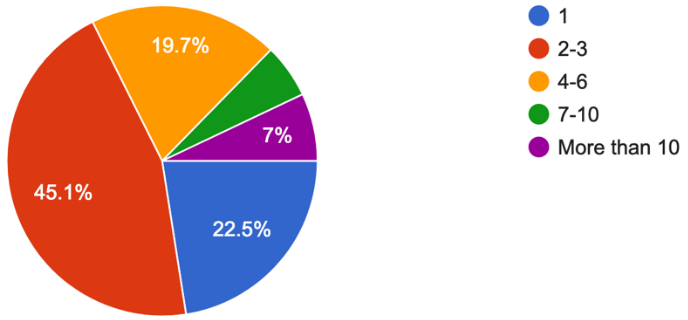
17. Are you in regular contact with other Go-Lab teachers outside of your country (e.g. through email, Facebook, physical meetings, etc.)?

71 responses



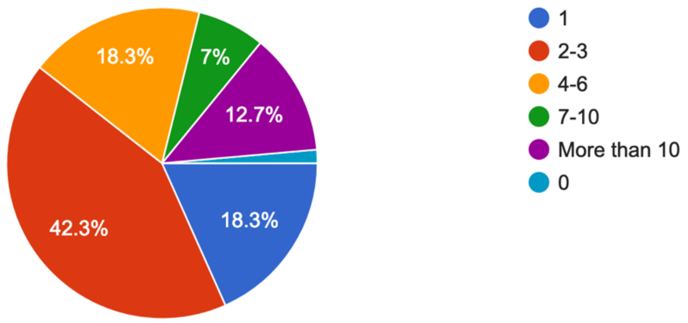
18. How many of ILSs have you created in Graasp?

71 responses



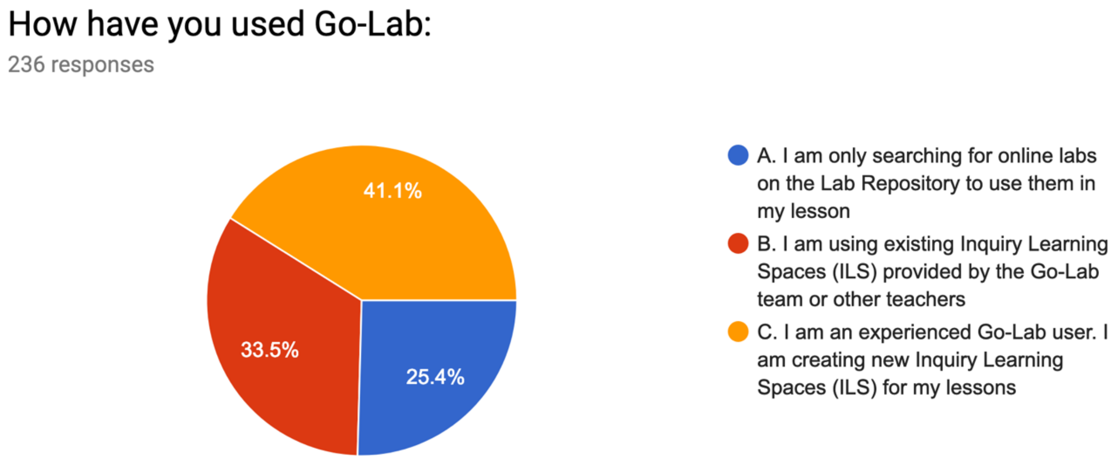
19. How many of ILSs have you implemented in an educational setting (formal and informal)?

71 responses

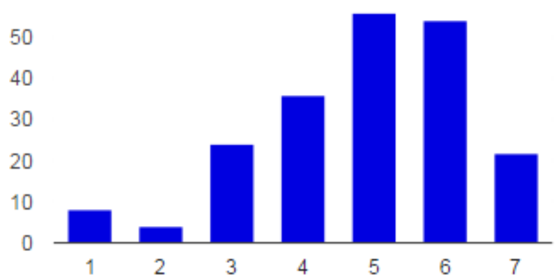


Appendix V Summary of the Answers to the Go-Lab Online Surveys

(Phase I)

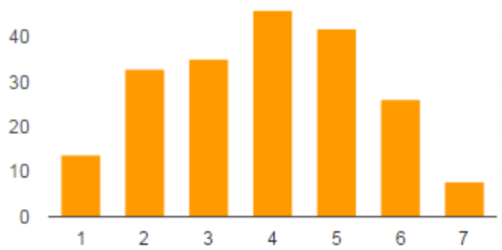


1. To what extent do you think that the Go-Lab tools are supporting your teaching practice?



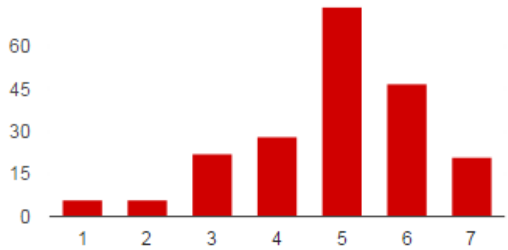
Not at all: 1	**8**	3.9%
2	**4**	2%
3	**24**	11.8%
4	**36**	17.6%
5	**56**	27.5%
6	**54**	26.5%
A lot: 7	**22**	10.8%

2. With Go-Lab I have the opportunity to introduce lab work in almost every lesson

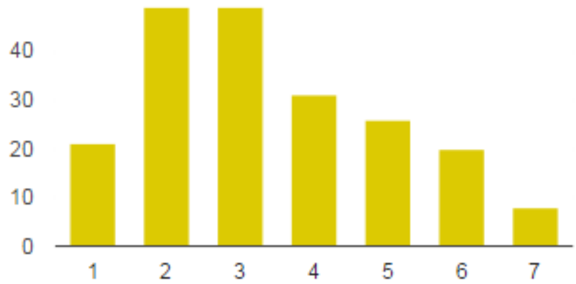


Strongly Disagree: 1	**14**	6.9%
2	**33**	16.2%
3	**35**	17.2%
4	**46**	22.5%
5	**42**	20.6%
6	**26**	12.7%
Strongly agree: 7	**8**	3.9%

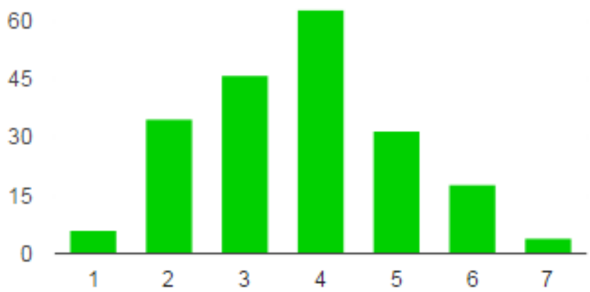
3. In the table below you will find 10 pairs of contrasting attributes. Where you place your choice between two attributes indicates your view about the quality of [the Go-Lab Portal]. This choice tells us that the Go-Lab Portal is somewhat likeable, but there is still room for improvement (Note: There is no right or wrong answer. Your personal opinion is what counts.)



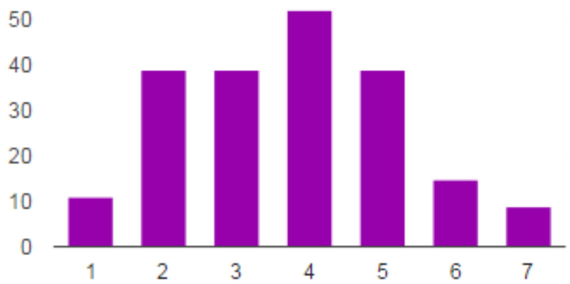
Confusing: 1	**6**	2.9%
2	**6**	2.9%
3	**22**	10.8%
4	**28**	13.7%
5	**74**	36.3%
6	**47**	23%
Structured: 7	**21**	10.3%



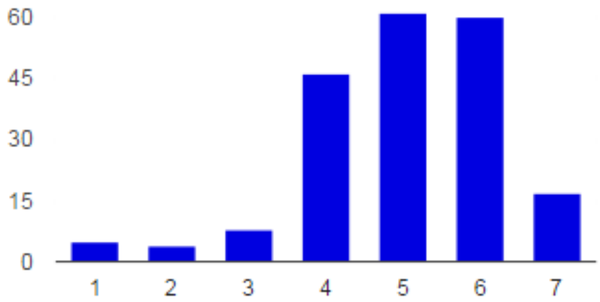
Practical: 1	**21**	10.3%
2	**49**	24%
3	**49**	24%
4	**31**	15.2%
5	**26**	12.7%
6	**20**	9.8%
Impractical: 7	**8**	3.9%



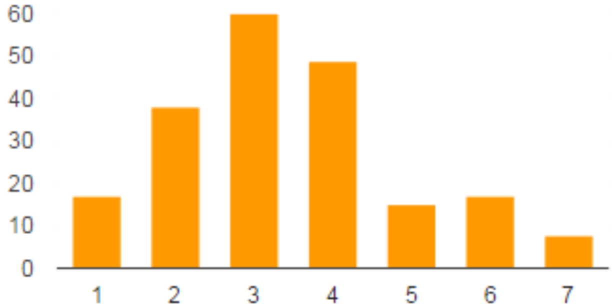
Predictable: 1	**6**	2.9%
2	**35**	17.2%
3	**46**	22.5%
4	**63**	30.9%
5	**32**	15.7%
6	**18**	8.8%
Unpredictable: 7	**4**	2%



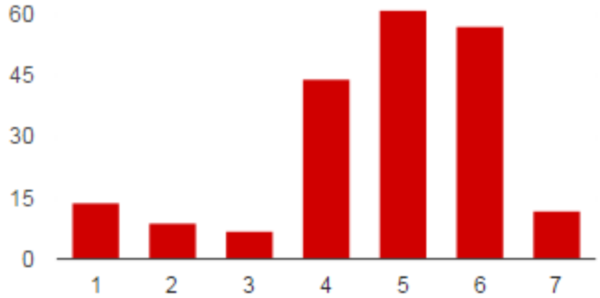
Simple: 1	**11**	5.4%
2	**39**	19.1%
3	**39**	19.1%
4	**52**	25.5%
5	**39**	19.1%
6	**15**	7.4%
Complicated: 7	**9**	4.4%



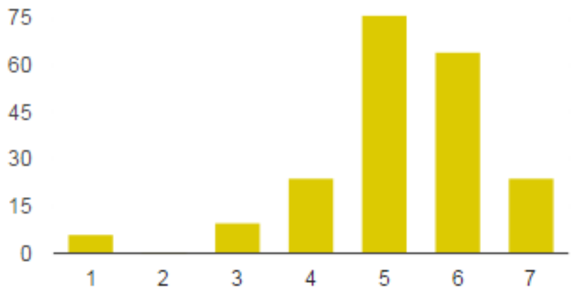
Dull: 1	**5**	2.5%
2	**4**	2%
3	**8**	4%
4	**46**	22.9%
5	**61**	30.3%
6	**60**	29.9%
Captivating: 7	**17**	8.5%



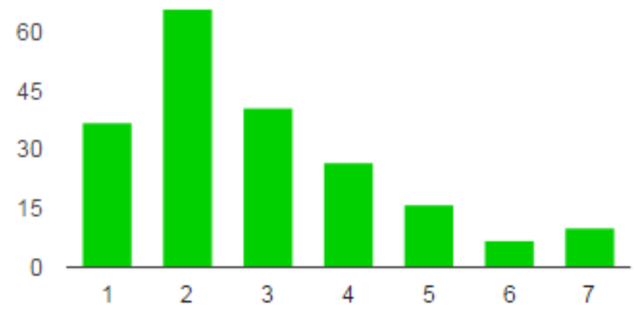
Stylish: 1	**17**	8.3%
2	**38**	18.6%
3	**60**	29.4%
4	**49**	24%
5	**15**	7.4%
6	**17**	8.3%
Tacky: 7	**8**	3.9%



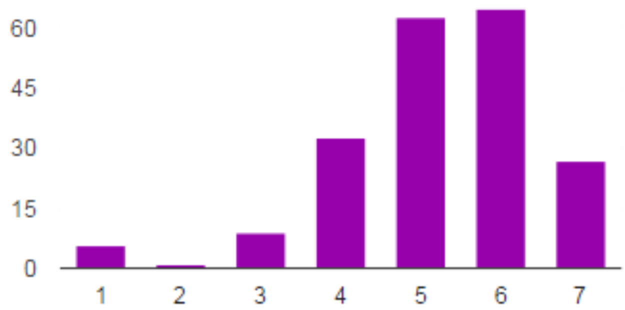
Cheap: 1	**14**	6.9%
2	**9**	4.4%
3	**7**	3.4%
4	**44**	21.6%
5	**61**	29.9%
6	**57**	27.9%
Premium: 7	**12**	5.9%



Unimaginative: 1	**6**	2.9%
2	**0**	0%
3	**10**	4.9%
4	**24**	11.8%
5	**76**	37.3%
6	**64**	31.4%
Creative: 7	**24**	11.8%



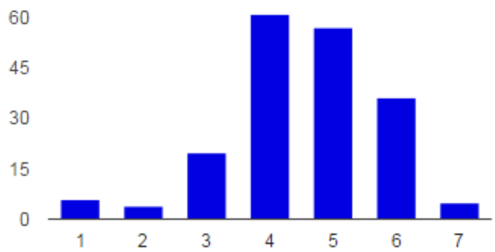
Good: 1	**37**	18.1%
2	**66**	32.4%
3	**41**	20.1%
4	**27**	13.2%
5	**16**	7.8%
6	**7**	3.4%
Bad: 7	**10**	4.9%



Ugly: 1	**6**	2.9%
2	**1**	0.5%
3	**9**	4.4%
4	**33**	16.2%
5	**63**	30.9%
6	**65**	31.9%
Beautiful: 7	**27**	13.2%

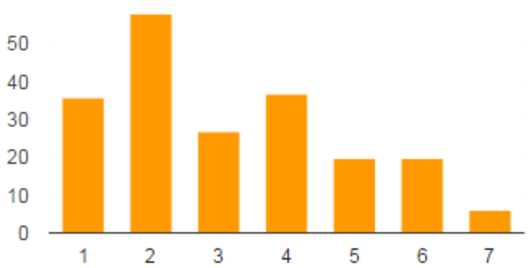
4. For each of the following statements, please indicate your extent of agreement by circling the number of choice

[The Go-Lab Portal's] capabilities meet my requirements.



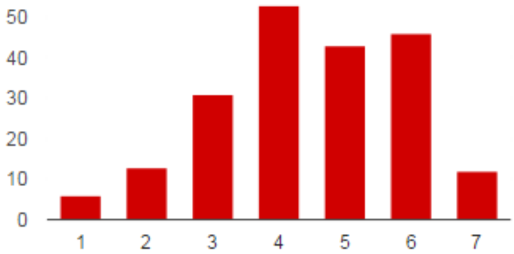
Strongly Disagree: 1	**6**	3.2%
2	**4**	2.1%
3	**20**	10.6%
4	**61**	32.3%
5	**57**	30.2%
6	**36**	19%
Strongly Agree: 7	**5**	2.6%

Using [the Go-Lab Portal] is a frustrating experience.



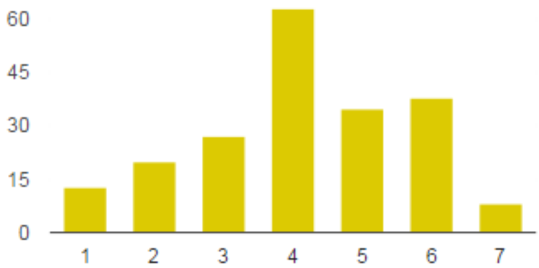
Strongly Disagree: 1	**36**	17.6%
2	**58**	28.4%
3	**27**	13.2%
4	**37**	18.1%
5	**20**	9.8%
6	**20**	9.8%
Strongly Agree: 7	**6**	2.9%

[The Go-Lab Portal] is easy to use.



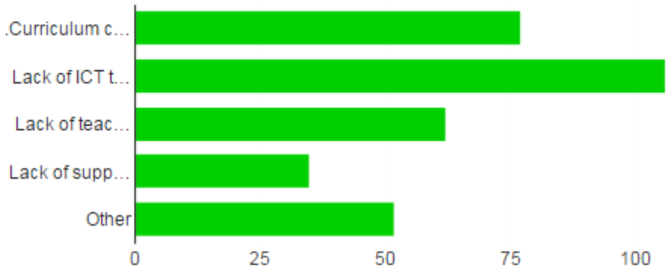
Strongly Disagree: 1	**6**	2.9%
2	**13**	6.4%
3	**31**	15.2%
4	**53**	26%
5	**43**	21.1%
6	**46**	22.5%
Strongly Agree: 7	**12**	5.9%

I have to spend too much time working with [the Go-Lab Portal].



Strongly Disagree: 1	**13**	6.4%
2	**20**	9.8%
3	**27**	13.2%
4	**63**	30.9%
5	**35**	17.2%
6	**38**	18.6%
Strongly Agree: 7	**8**	3.9%

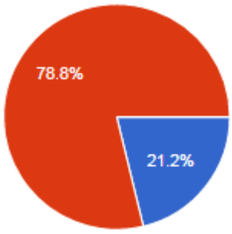
5. What barriers can you identify in introducing Go-Lab in your classroom activities? (choose one or more options)



.Curriculum compatibility – The proposed activities are not part of the curriculum	**77**	37.7%
Lack of ICT tools in classroom – There are no computers for every student	**106**	52%
Lack of teachers' ICT literacy – Too demanding for me	**62**	30.4%
Lack of support from school	**35**	17.2%
Other	**52**	25.5%

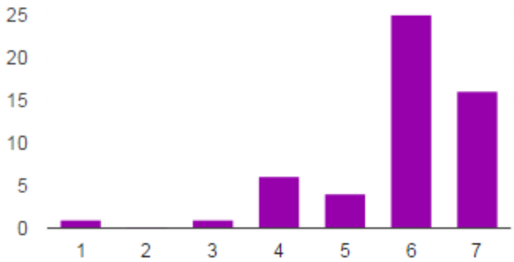
Types of use of Go - lab

6. The Go-Lab tutoring platform provides the opportunity to share your experiences with peers and get support while are you using Go-Lab. Have you used this service? – Yes -- No



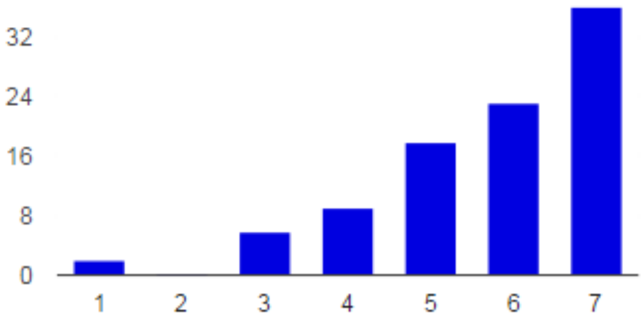
yes	**42**	20.6%
no	**156**	76.5%

1. If yes: Are you considering that the sharing of experiences and bets practices is also improving your practice with Go-Lab?



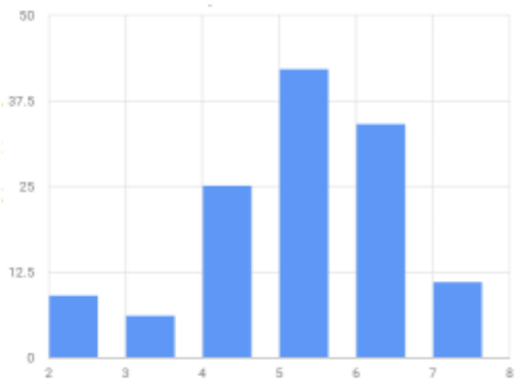
Not at all: 1	**1**	1.9%
2	**0**	0%
3	**1**	1.9%
4	**6**	11.3%
5	**4**	7.5%
6	**25**	47.2%
A lot: 7	**16**	30.2%

2. If no: Would you like to share your ILSs with other teachers using Go-Lab?



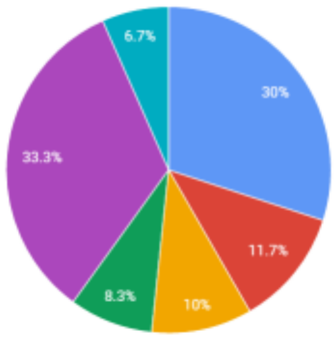
No! I do not like to share my resources: 1	**2**	2.1%
2	**0**	0%
3	**6**	6.4%
4	**9**	9.6%
5	**18**	19.1%
6	**23**	24.5%
Yes! Sharing our experiences is the best resource we have: 7	**36**	38.3%

7. Do you think that the ILSs that have been developed by the GoLab team are supporting your practice and covering your teaching needs? (only for B and C modes of use)



Not at all: 1	**0**	
2	**9**	7%
3	**6**	4.7%
4	**25**	19.6%
5	**42**	33%
6	**34**	26.7%
7	**11**	8.6%
A lot: 7	**12**	7.6%

8. Do you think that you can use Graasp systematically in order to create ILSs to be used in your teaching practice? (only for C mode of use)



Not at all: 1	**0**	
2	**5**	8.3%
3	**4**	6.7%
4	**7**	11.7%
5	**18**	30%
6	**20**	33.3%
7	**6**	10%
A lot: 7	**8**	7.7%

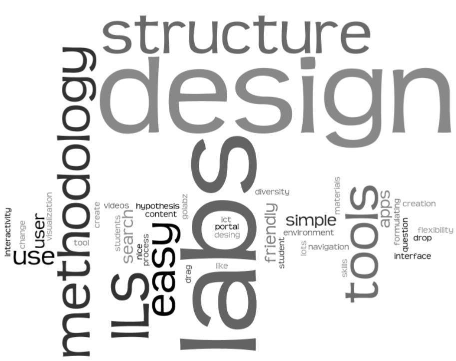
What did you find more challenging in creating your own ILSs?

In general the most common issues related to the obstacles met by the users when creating their ILSs were related to finding the appropriate lab and app that are adequate to be integrated in the curriculum, that allow them to use the proposed methodology in the provided time available.

What did you like most about the Go-Lab activities you have implemented?

For those teachers that implemented or tested the model with students the most common comment was that students were much more motivated when exposed to the proposed ILS. They enjoyed "playing" with the labs and found the apps very appealing. Some students manifested the wish to create ILSs themselves.

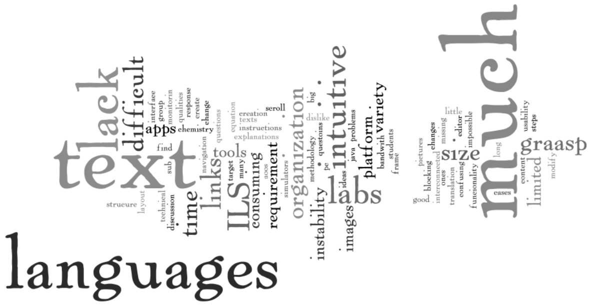
In the text box below, please comment on your most liked and most disliked design of the user interface of Go-Lab you have just used:



Liked

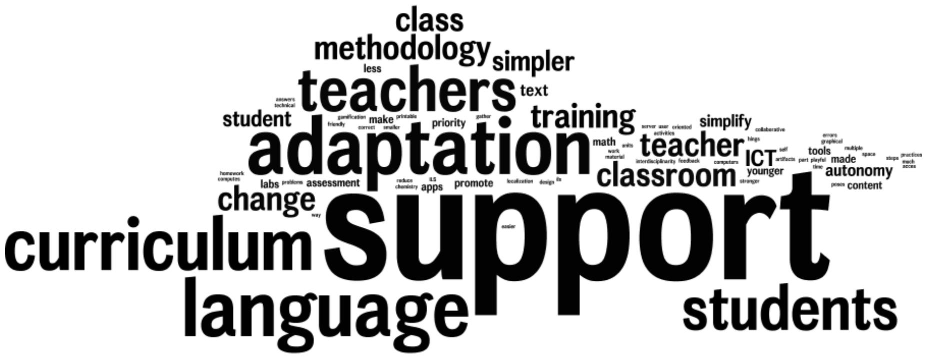
Teachers in general appreciated the structure being used to present the tools and resources. They found the methodology very appropriate to engage their students in a different and innovative way. They found that the authoring tool was really facilitating the process of creating their ILS. In general they said that once they understand the process it becomes user-friendly.

Disliked



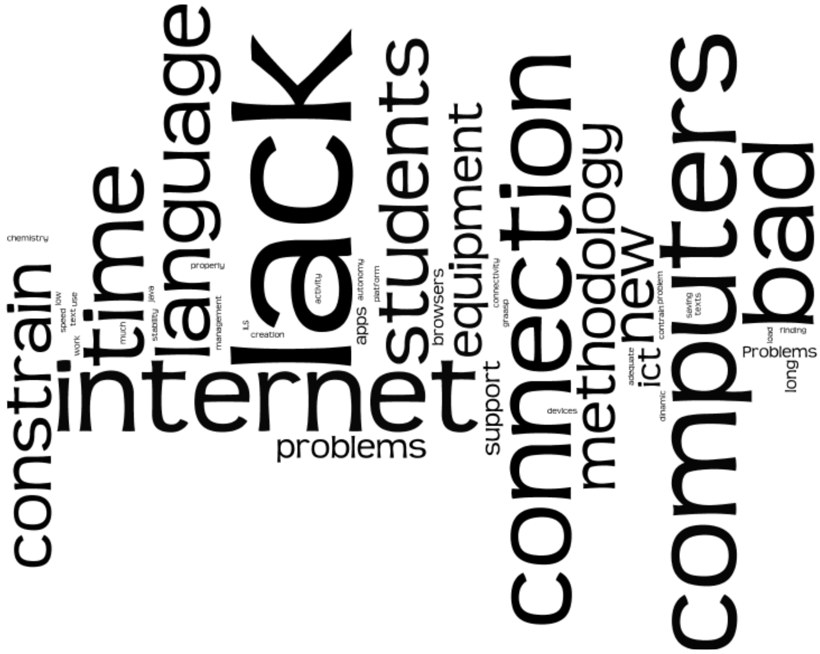
A common comment was the fact that the portal and the authoring tool were different structures. They felt the need to have the labs text translated to their language and commented that several ILSs were not very intuitive.

What are the necessary pedagogical changes in order for Go-Lab to be more efficient to your teaching practice?



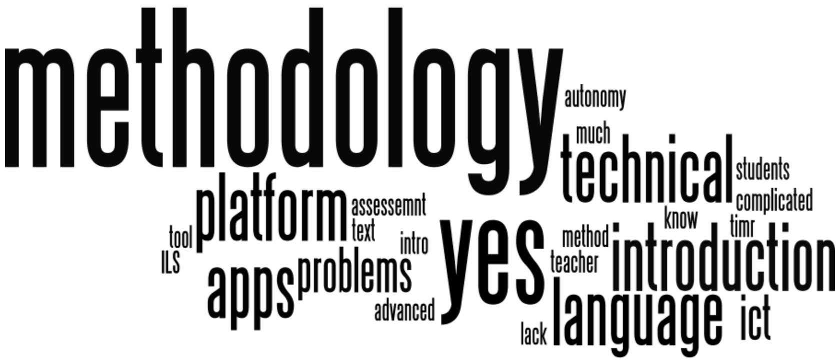
Teachers in general requested continuous support for the learning and implementation of Go-lab in classroom. Translation and localization scored high in their suggestions and adaptation to their curriculum a very important aspect for their full adoption of the system.

What difficulties did you encountered when implementing the Go-Lab activity in the classroom?



When addressing the issue of difficulties the most common issue is without question the lack of ICT infrastructure and support. Also the lack of proper internet connection and time constrain. Language appeared very often.

Did students need explanations/support (more than expected) in order to perform the Go-Lab activity. If yes, please specify

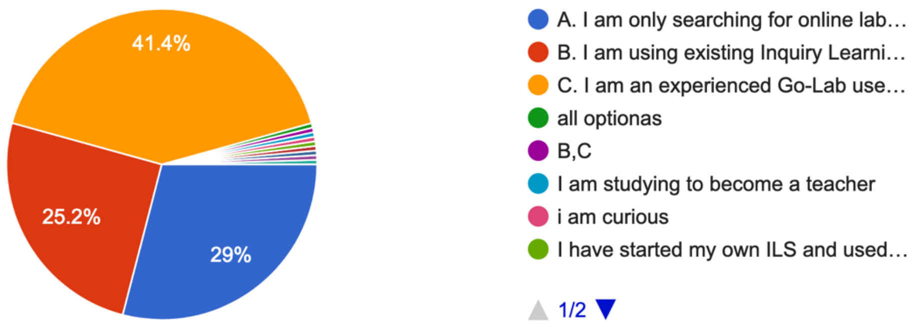


Students are not comfortable in general with the IB methodology. The process requires repetition and more instances of use in order to have the students really engaging in the process. Issues with language and localization were also mentioned several times.

(Phase II)

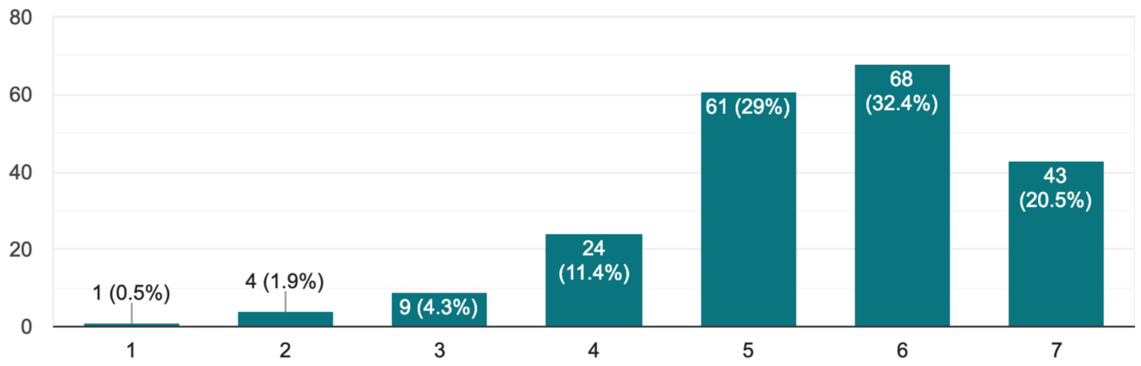
With which of the following options would you identify the most regarding the use of Go-Lab :

210 responses



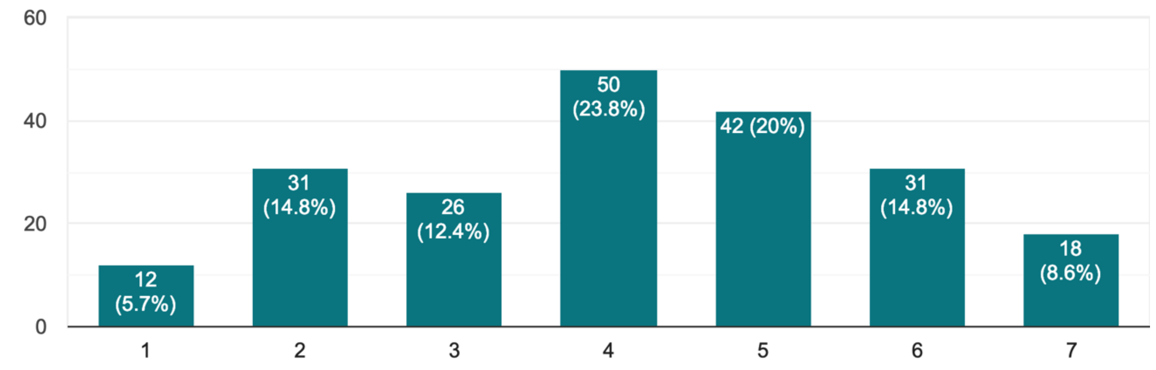
1. To what extent do you think that the Go-Lab tools have supported your teaching practice?

210 responses



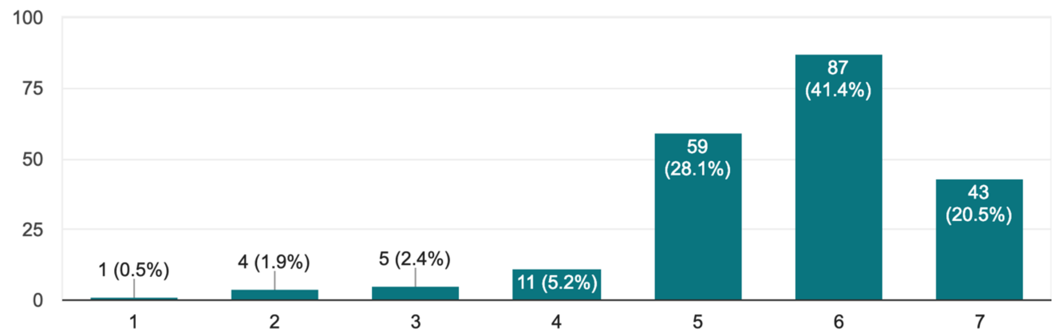
2. With Go-Lab I have had the opportunity to introduce labs work in almost every lesson

210 responses



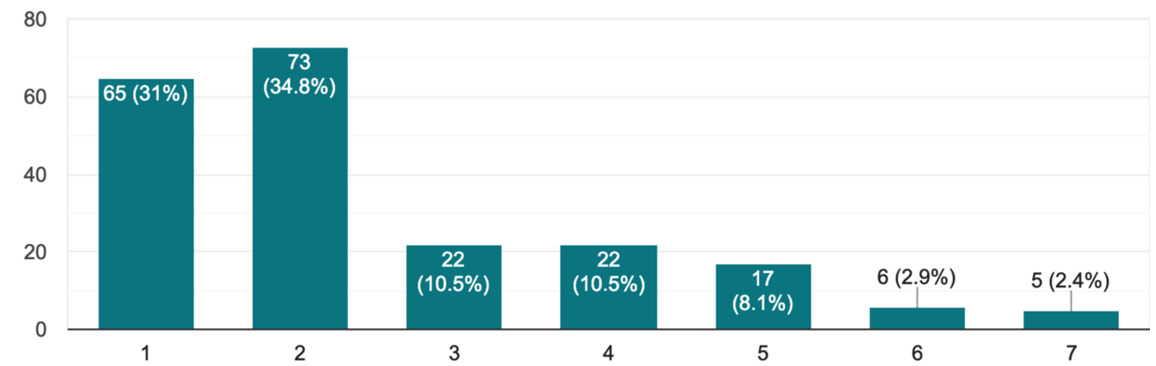
[The Go-Lab Portal's] capabilities have met my requirements.

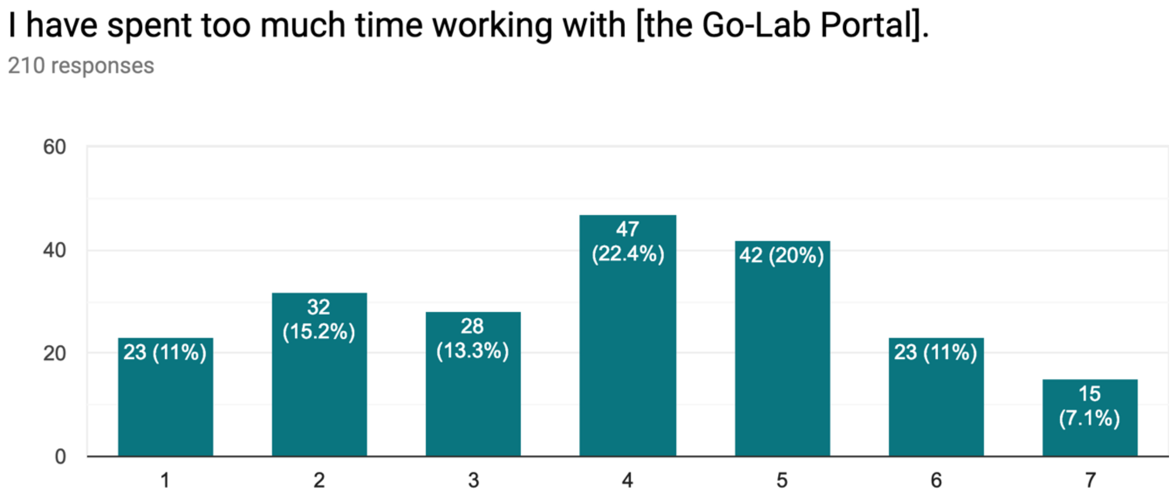
210 responses

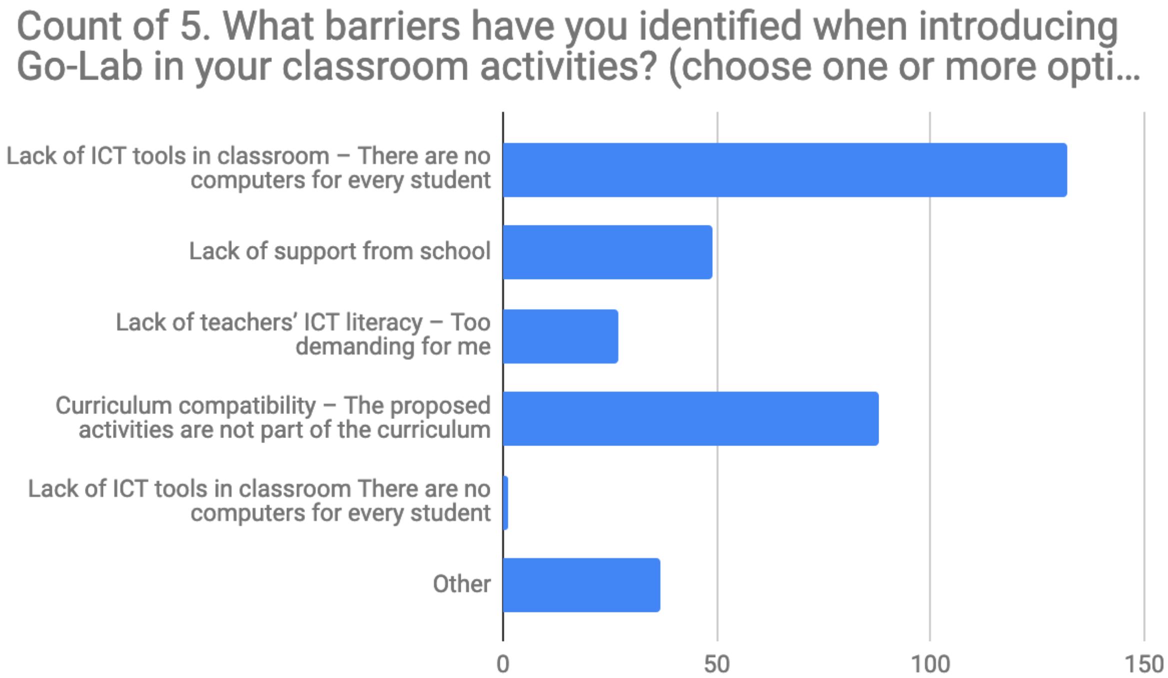


Using [the Go-Lab Portal] has been a frustrating experience.

210 responses

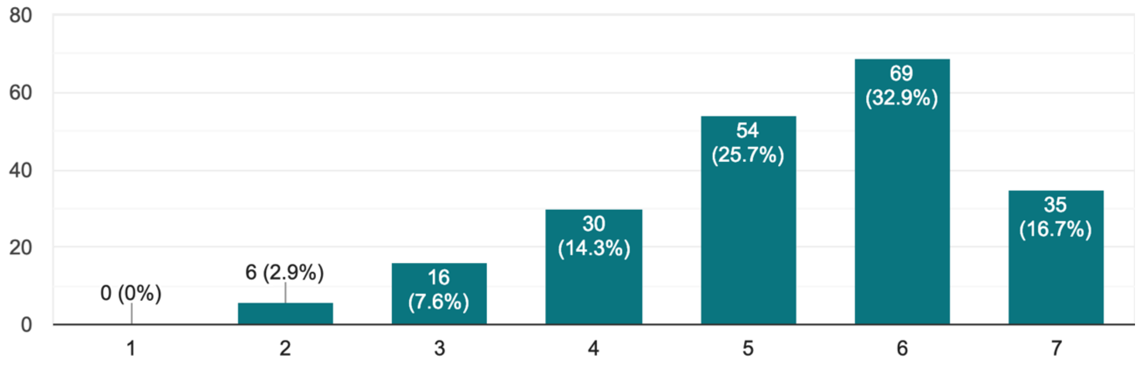



I have spent too much time working with [the Go-Lab Portal].
210 responses
60
40
20
0
23 (11%)
32 (15.2%)
28 (13.3%)
47 (22.4%)
42 (20%)
23 (11%)
15 (7.1%)
1
2
3
4
5
6
7


Count of 5. What barriers have you identified when introducing Go-Lab in your classroom activities? (choose one or more opti...
Lack of ICT tools in classroom – There are no computers for every student
Lack of support from school
Lack of teachers' ICT literacy – Too demanding for me
Curriculum compatibility – The proposed activities are not part of the curriculum
Lack of ICT tools in classroom There are no computers for every student
Other
0
50
100
150

[The Go-Lab Portal] is easy to use.

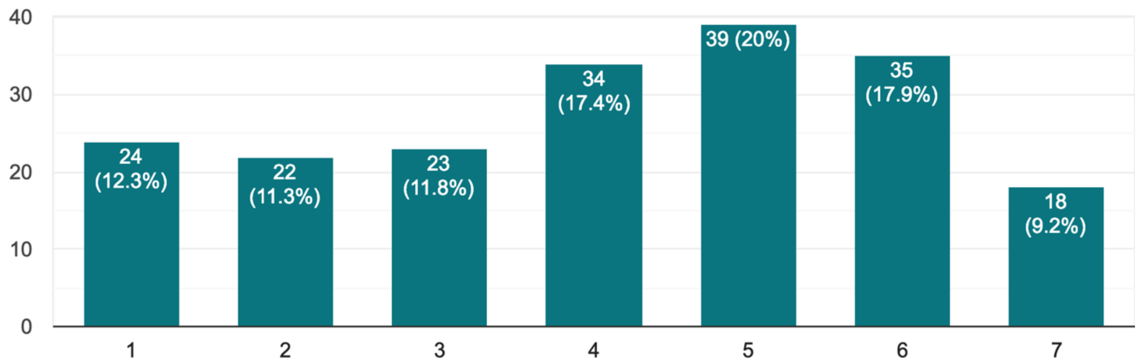
210 responses



6. How would you rate the support in the use of online laboratories via related trainings or other projects from...

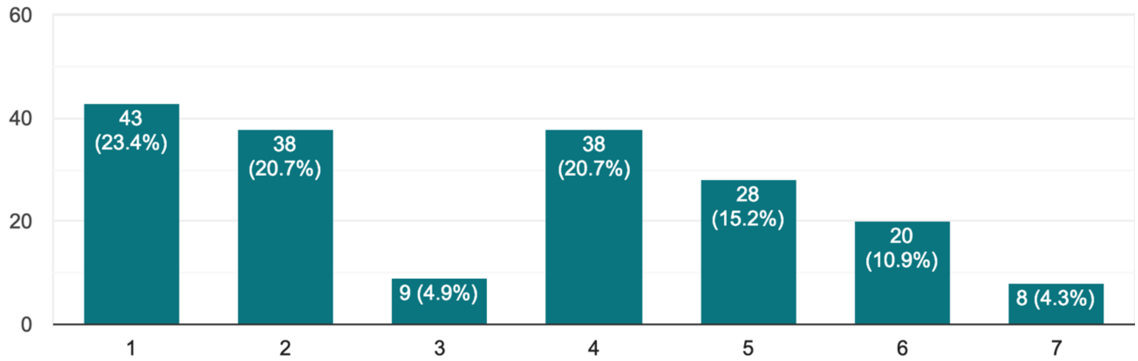
your school community?

195 responses



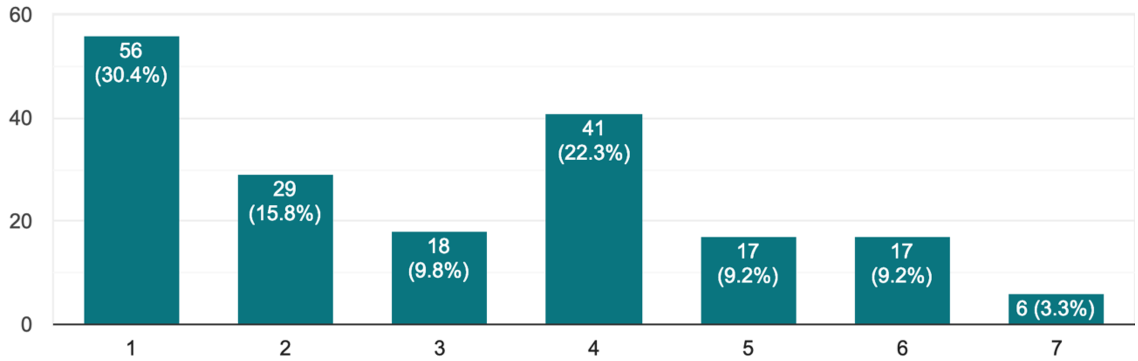
your local community?

184 responses



the Ministry of Education?

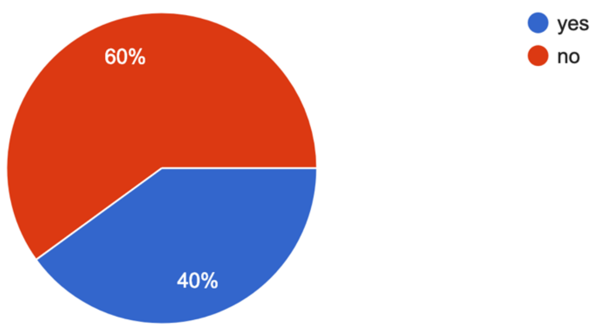
184 responses



Types of use of Go - lab

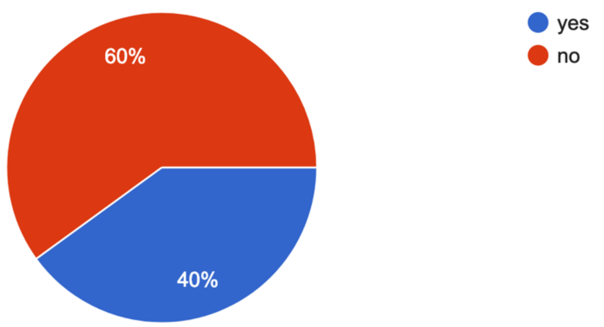
7. The Go-Lab tutoring platform provides the opportunity to share your experiences with peers and get support...ve you used this service? – Yes -- No

210 responses



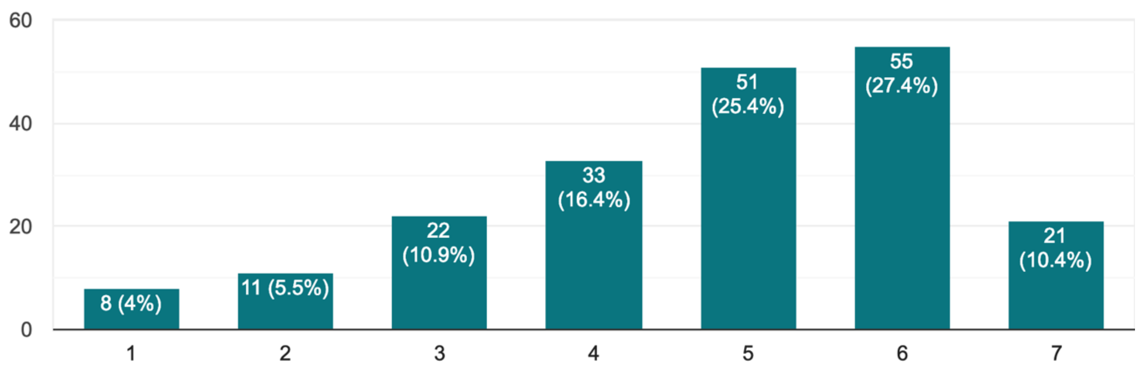
If yes: Have you published your own ILSs?

210 responses



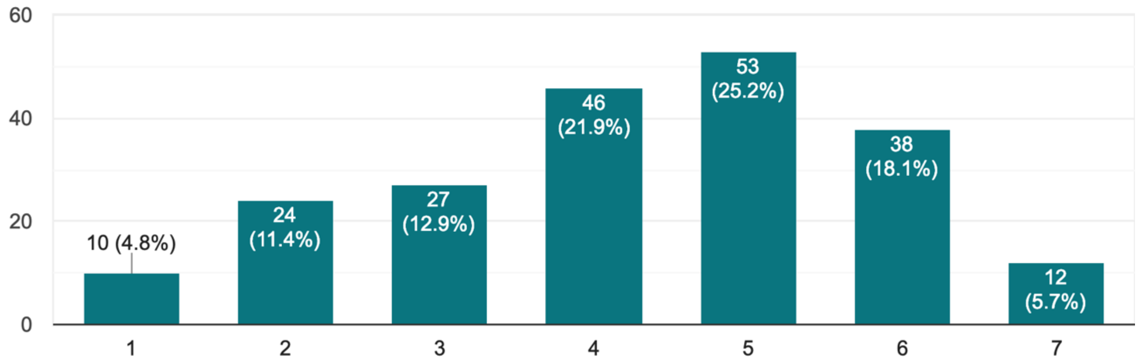
8. Do you think that the ILSs that have been developed by the GoLab team have supported your practice and covered your teaching needs?

201 responses



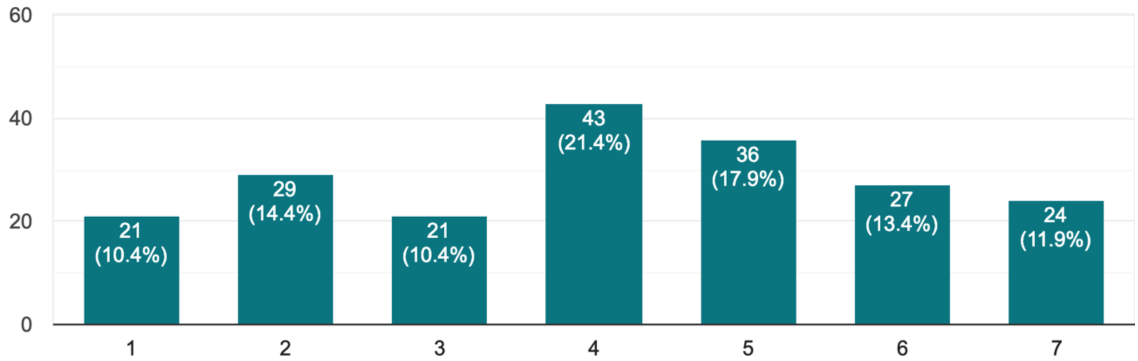
9. Would you describe the use of Graasp as easy?

210 responses



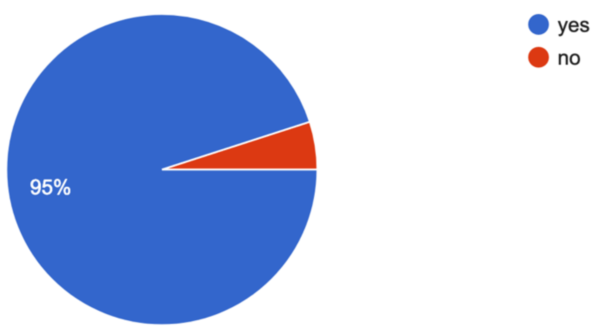
10. How useful have the "Big Ideas of Science" been for your lessons?

201 responses



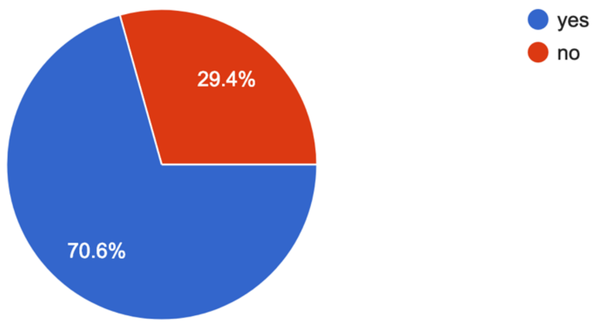
11. Will you continue using Go-Lab in your class?

201 responses



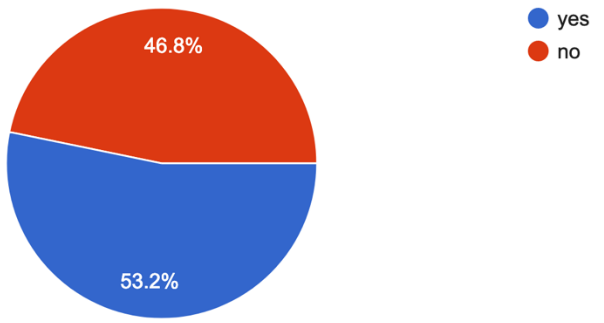
12. Has Go-Lab improved your knowledge of IBSE?

201 responses



13. Has the use of Go-Lab help you improve your ICT skills?

201 responses



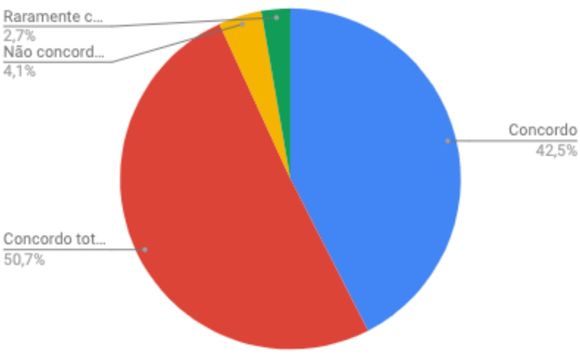
Appendix VI Results of Pre and Post Questionnaire Applied to the University of Coimbra's Students

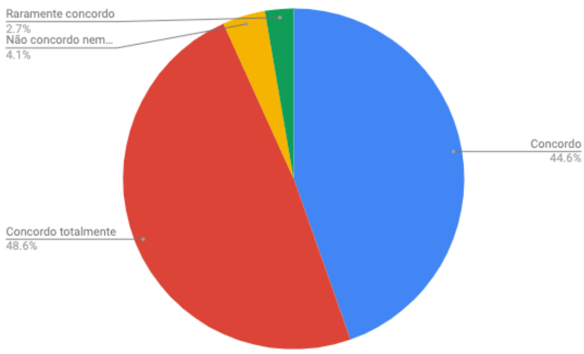
Teacher Education Master Course Answers (Pre Questionnaire – 68 responses Post – 76 responses)

Pre Training Questionnaire Post Training Questionnaire

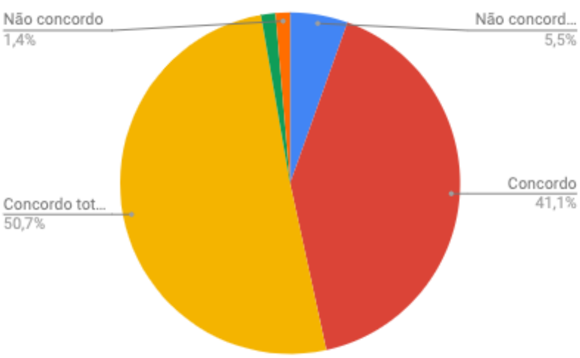
A teacher :

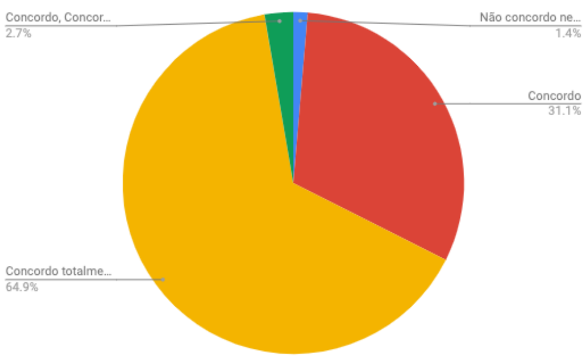
6.1 Is a facilitator of student's learning



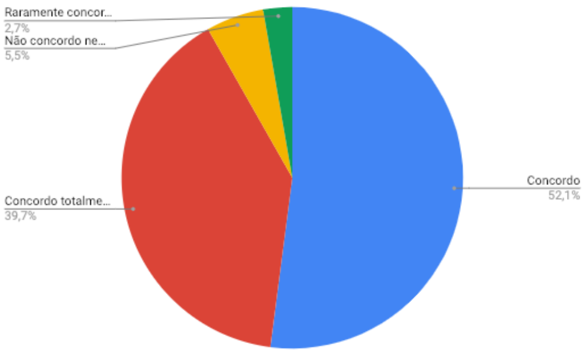


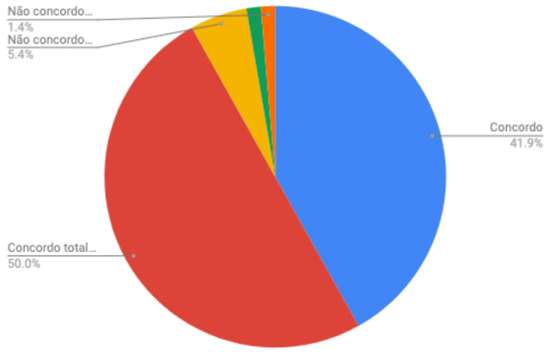
6.2 Receives the students' questions positively.



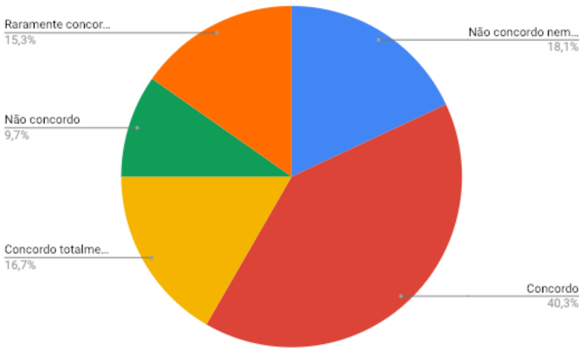


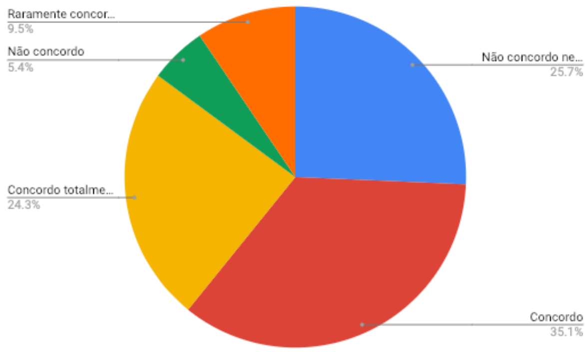
6.3 Encourages students to seek answers to their own questions.



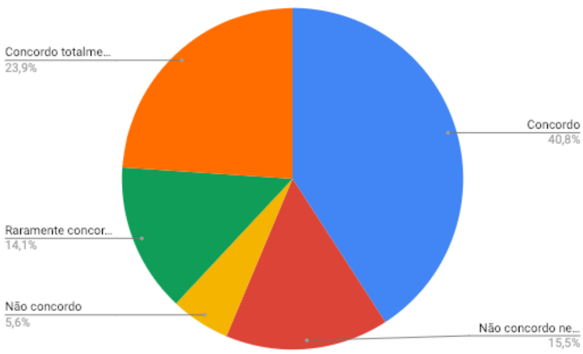


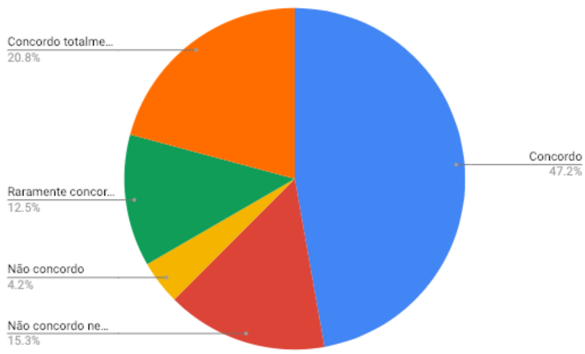
6.4 Ask students what they are interested in learning.



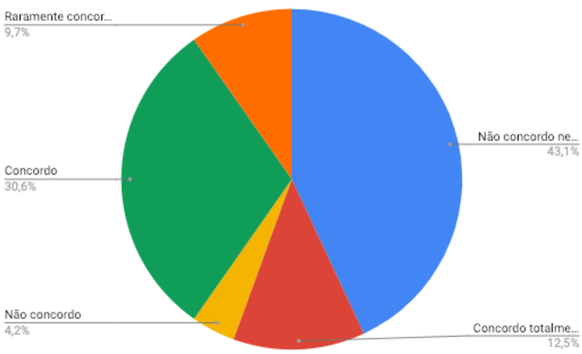


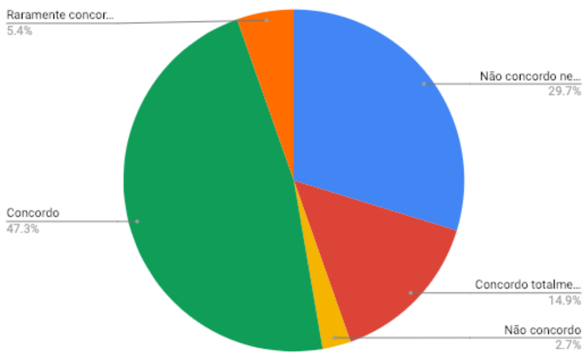
6.5 Students' interests are guides to building lessons.



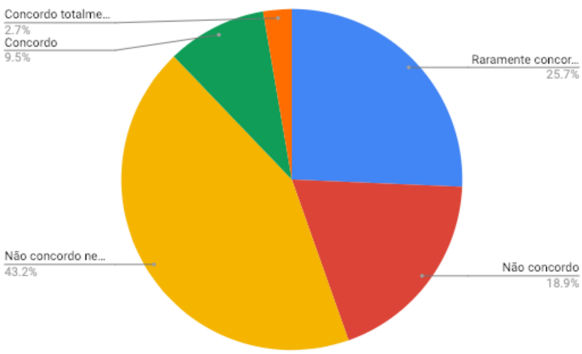


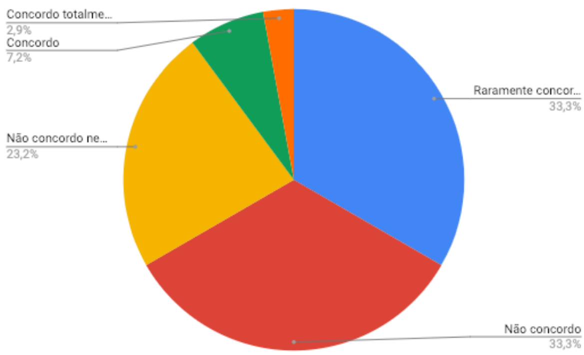
6.6 Uses discrepant events to motivate students.



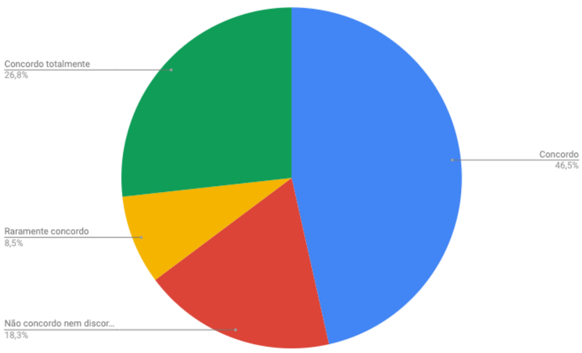


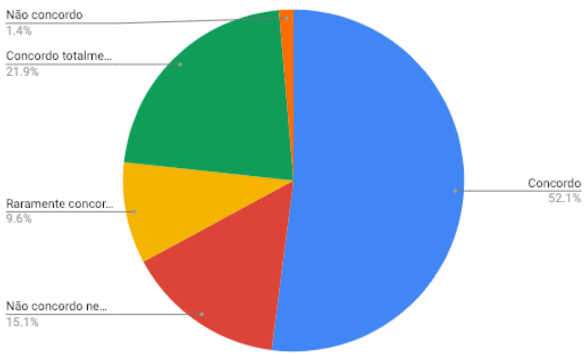
6.7 Does not use a school handbook.



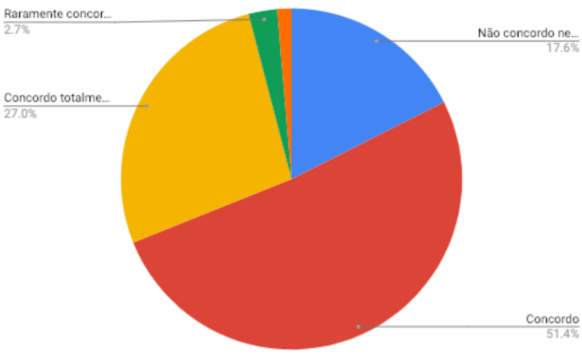


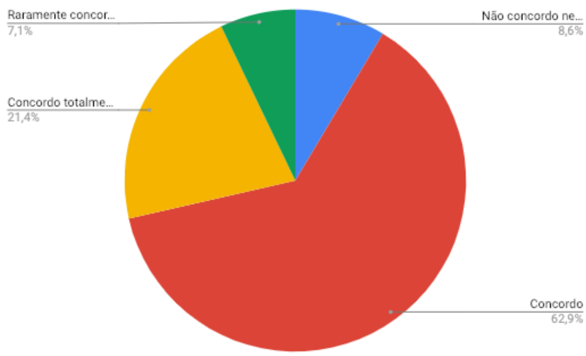
6.8 Focuses on students' understanding of concepts.



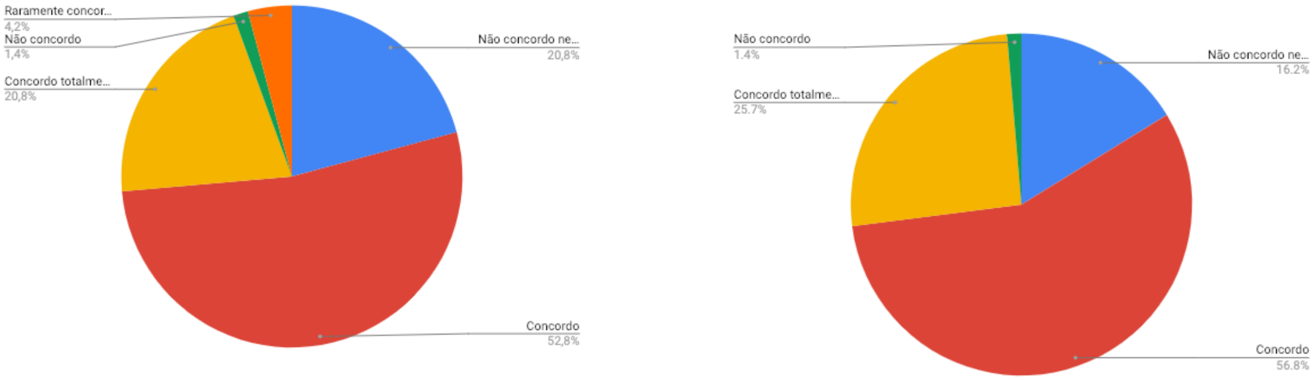


6.9 Involves students in the study of different research questions throughout the class.

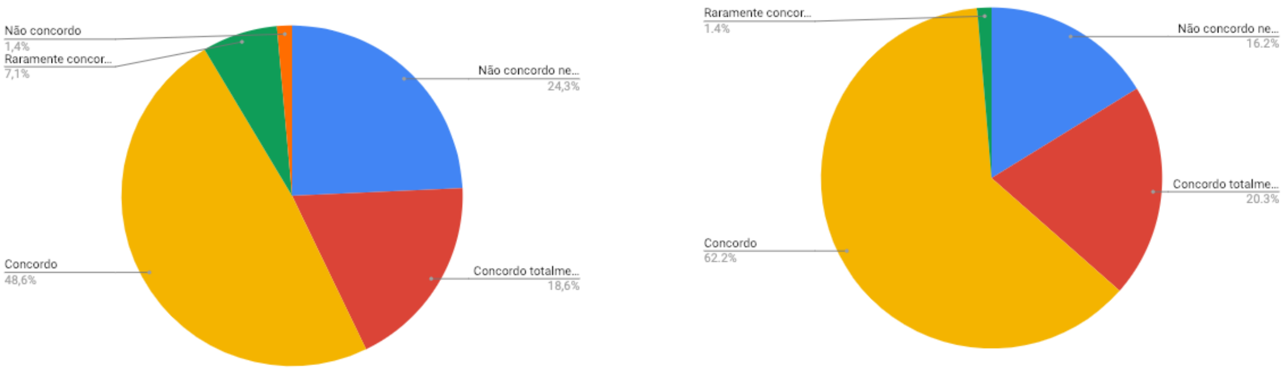




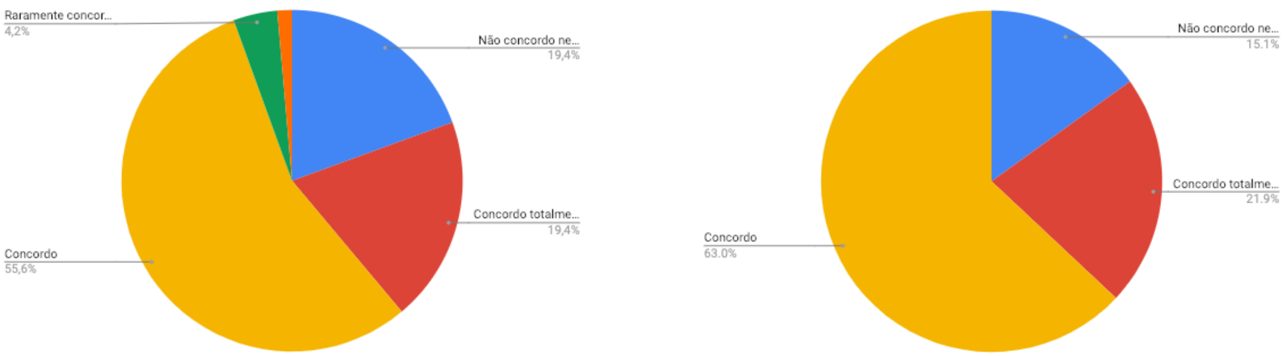
6.10 Asks students to develop their own hypotheses.



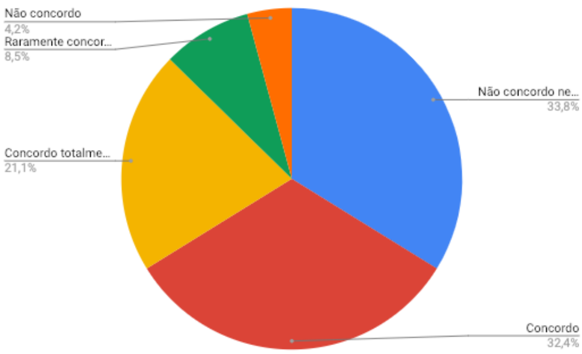
6.11 Asks students to develop their own experiences.

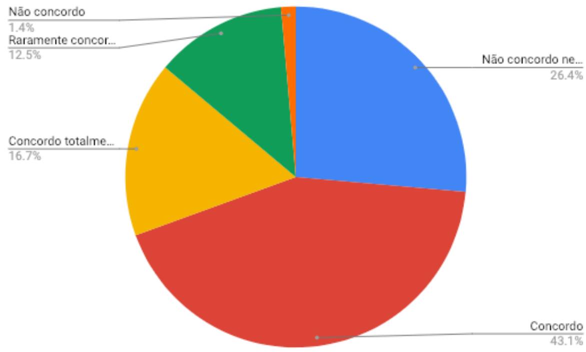


6.12 Asks students to analyze the data obtained during their experiments.

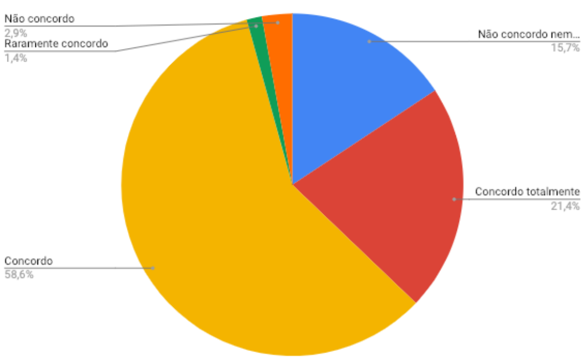


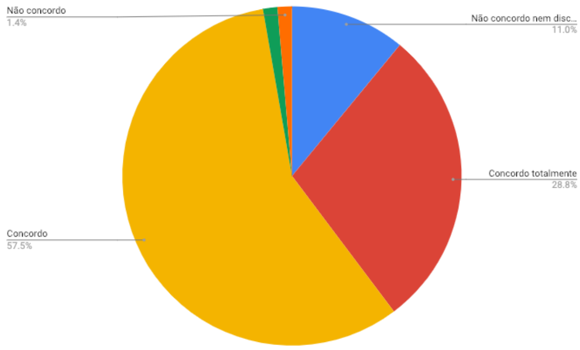
6.13 Asks students to read the research of other authors related to the current research before deciding what their research questions will be.



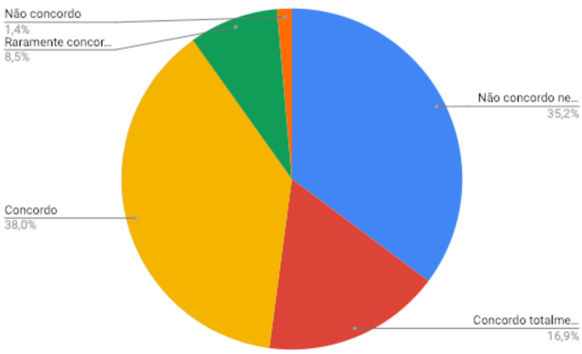


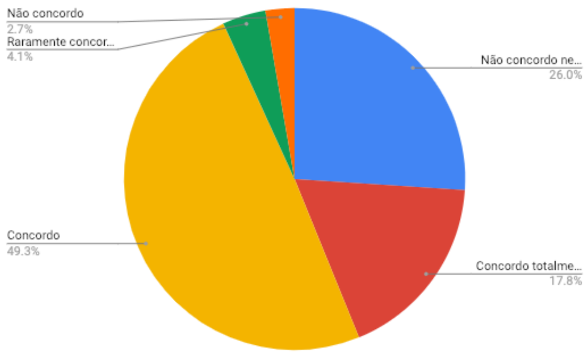
6.14 Invites students to present the results to their colleagues.



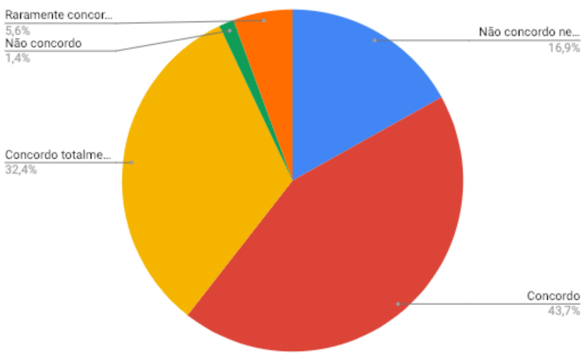


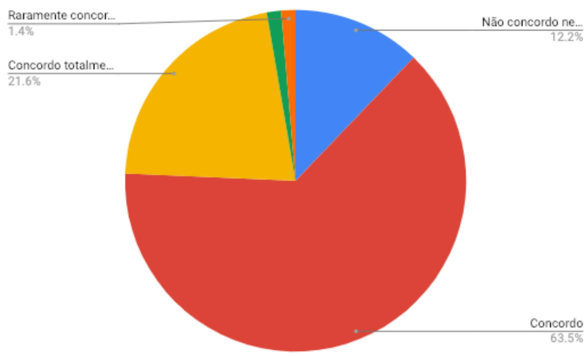
6.15 invites students to present the results of their research in an environment outside the classroom or school (eg fair, colloquium, conference, etc.).





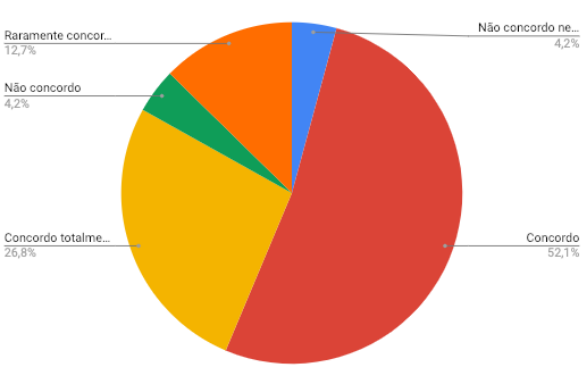
6.16 provides students with experiences that promote the development of research skills as well as the understanding of concepts.

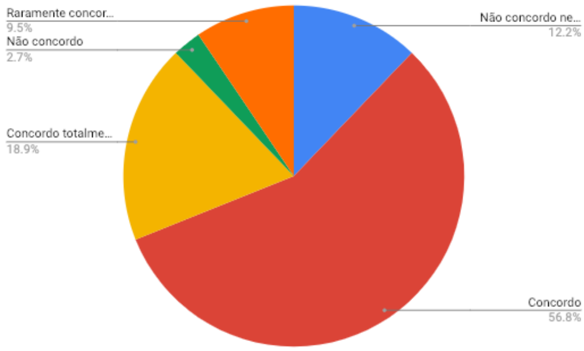




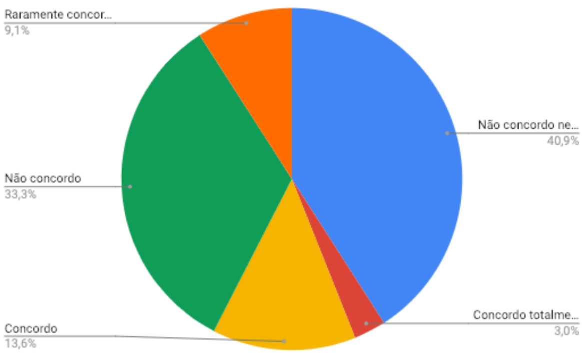
9. Please indicate your level of agreement with the following statements, considering the scale presented.

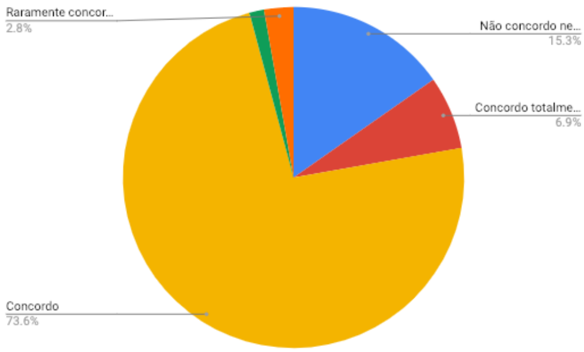
9.1 I have experience of using ICT in education.



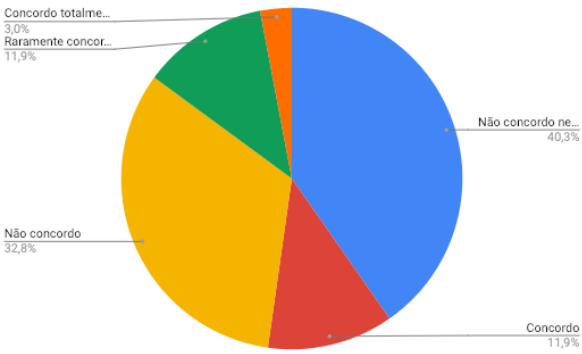


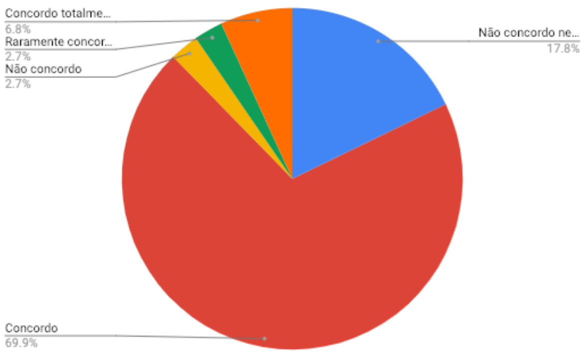
9.2.I have IBL knowledge that allows me to use it in the planning and implementation of educational activities.



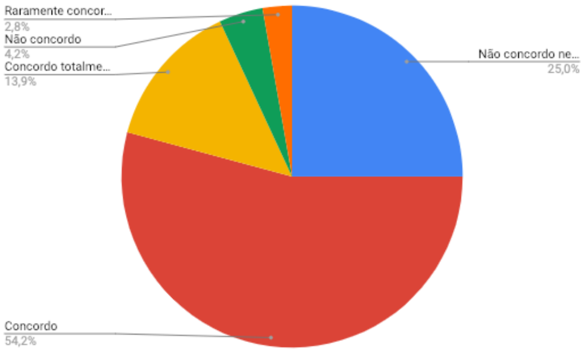


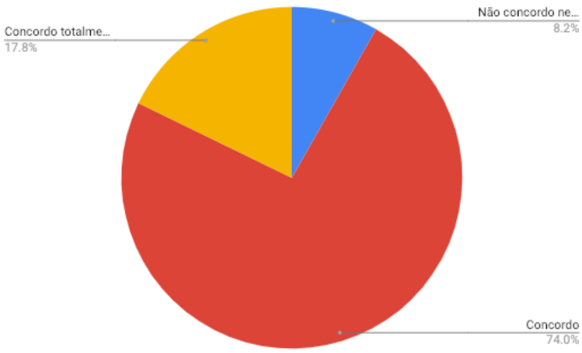
9.3. I know how to evaluate educational activities that use the IBL methodology.



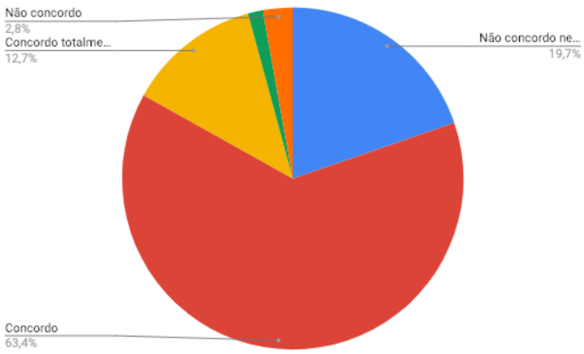


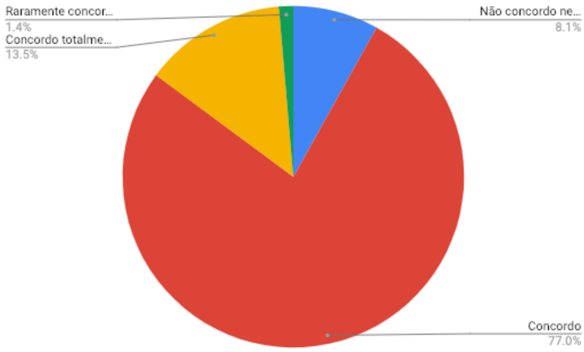
9.4.I have knowledge of various educational strategies



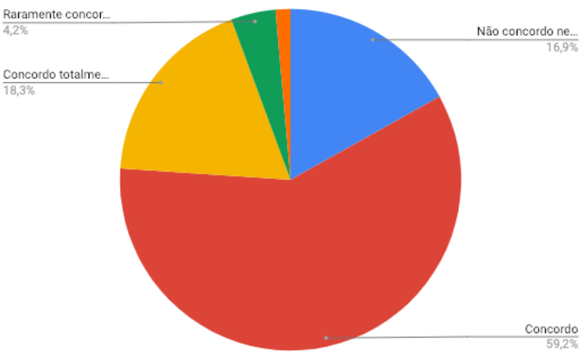


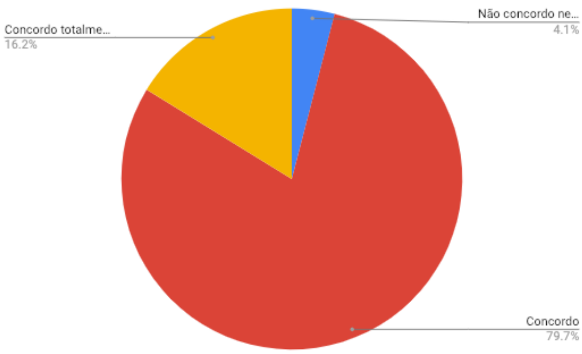
9.5. I know how to select effective educational approaches to promote active student involvement and cooperative learning.



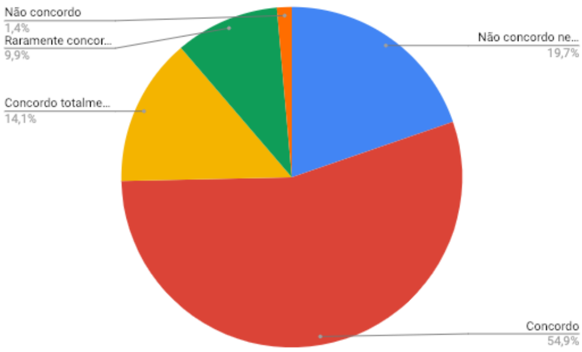


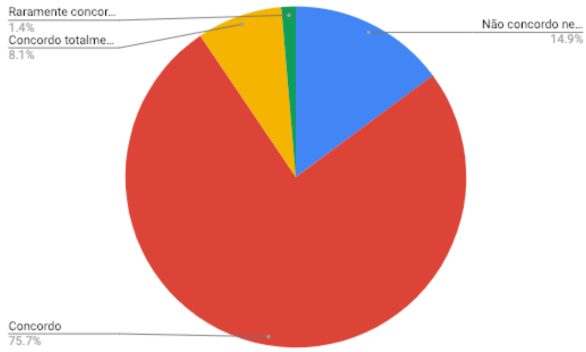
9.6.I am able to adapt strategies to different educational activities.



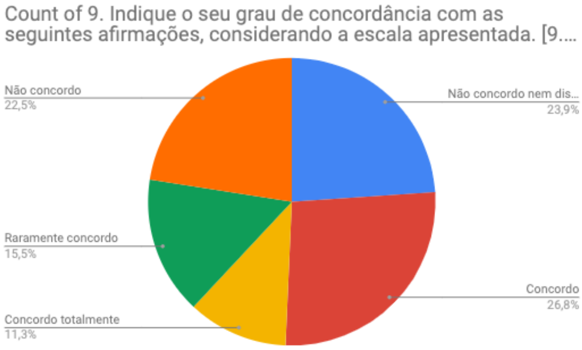


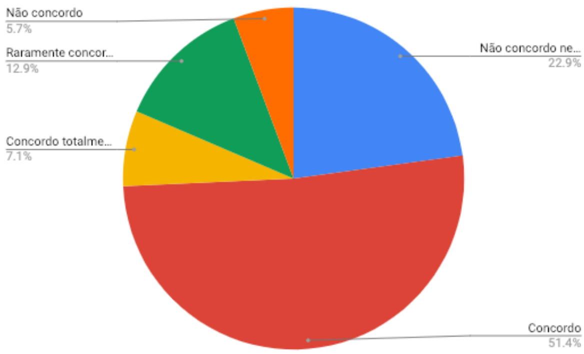
9.7 I know how to choose technological resources that evidence the contents.



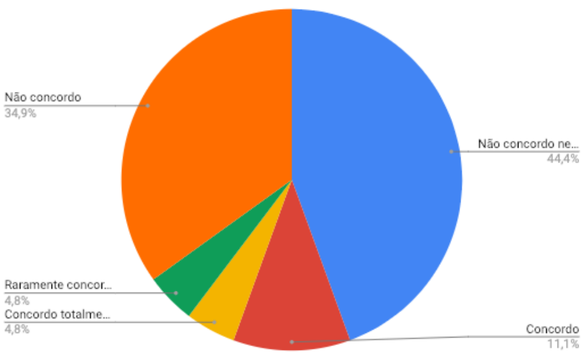


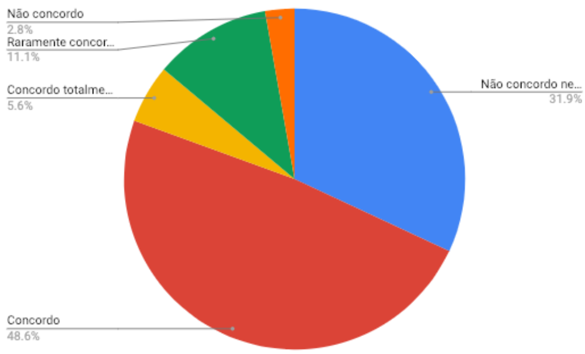
9.8.I have participated in training activities related to educational strategies.





9.9.I have experience in planning activities involving IBL and ICT

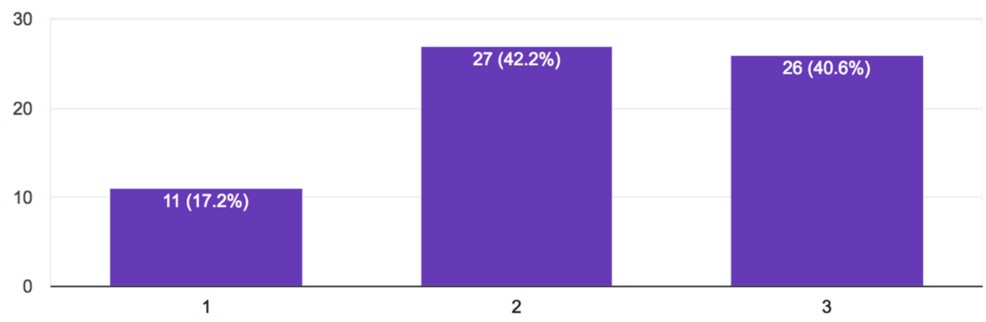




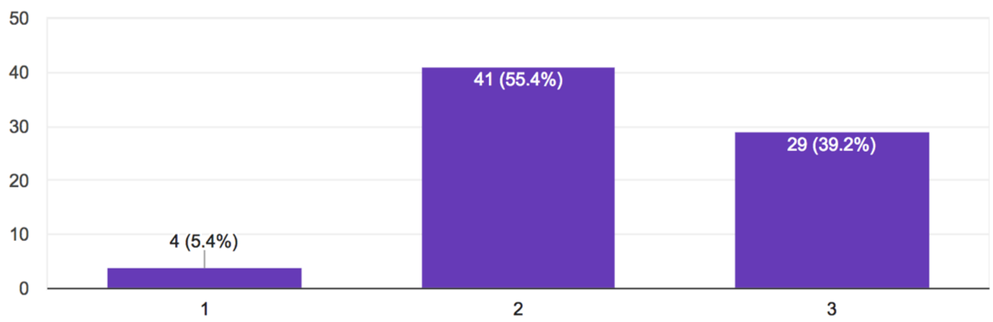
10. How do you characterize your usage of ICT for pedagogical purposes

Pre Training Questionnaire

1 – Low
3 – High



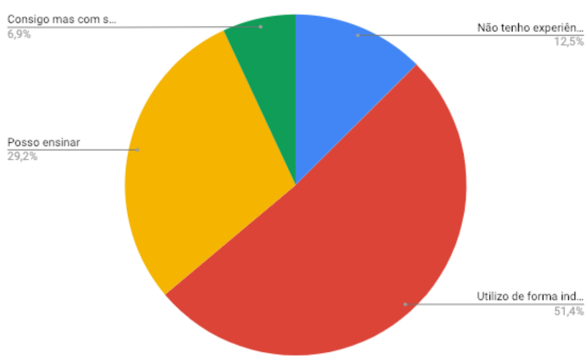
Post Training Questionnaire

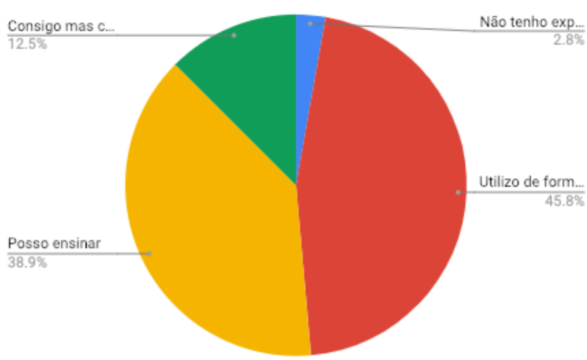


11. How do you characterize your degree of involvement with ICT?

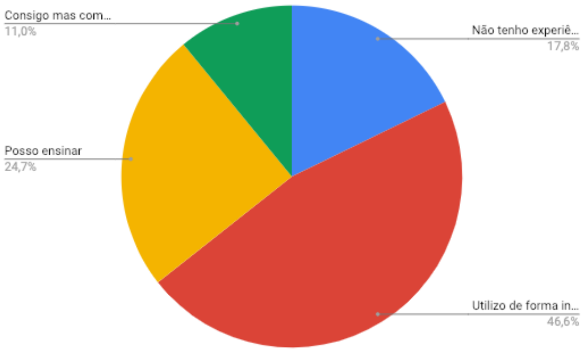
Pre Training Questionnaire | Post Training Questionnaire

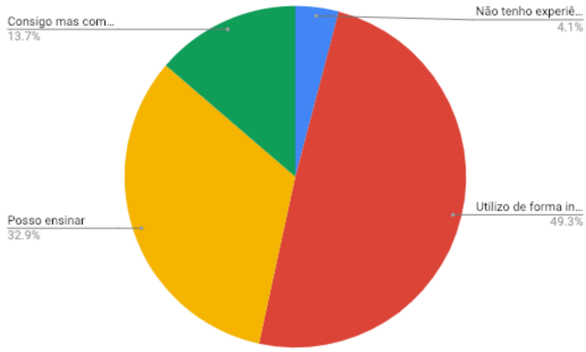
11.1. Using digital tools.



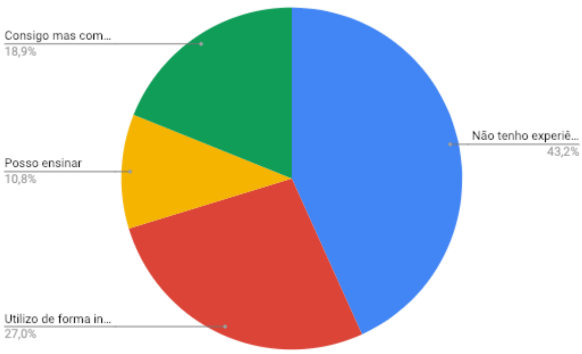


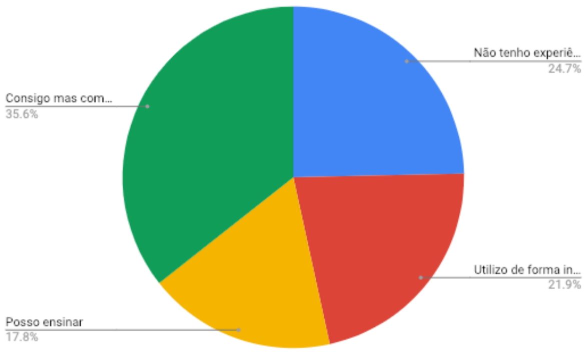
11.2. Use of educational material repositories.



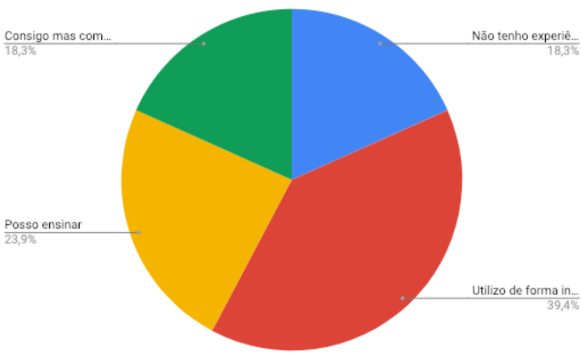


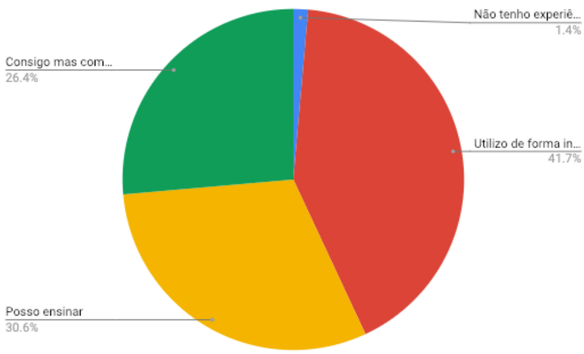
11.3. Use of laboratories and virtual simulations.





11.4.I appreciate exploring new tools and technologies.

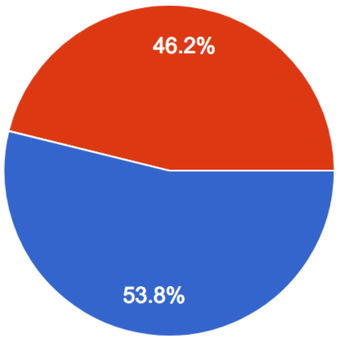


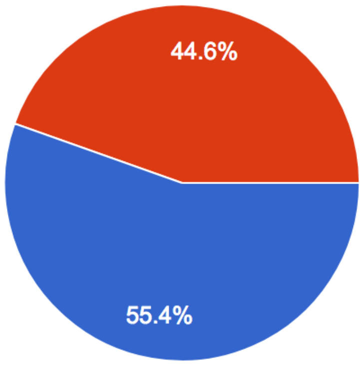


12. Please indicate which scenarios represent an inquiry learning activity.

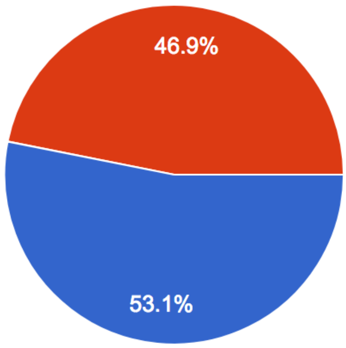
Pre Training Questionnaire ● yes ● no Post Training Questionnaire

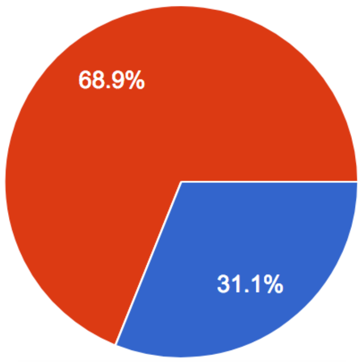
12.1 Students follow a protocol to develop an activity.



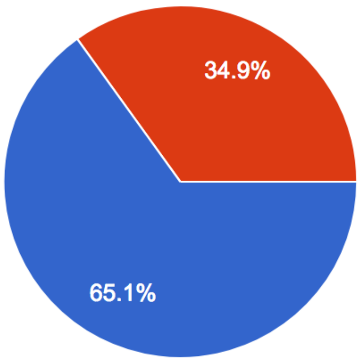


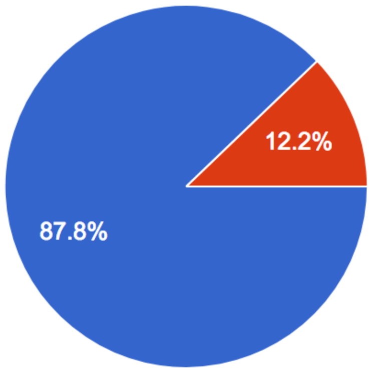
12.2 Students use an existing chart to explain a particular phenomenon.



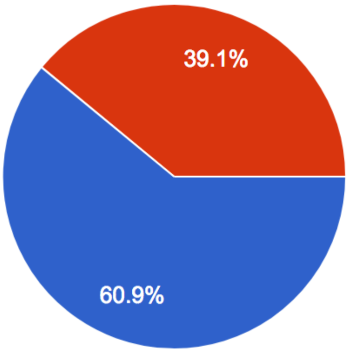


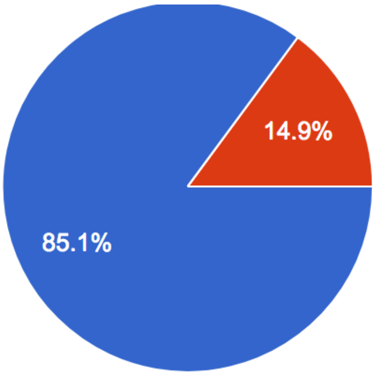
12.3 Students produce a graph to better characterize a recurring phenomenon in the local community.



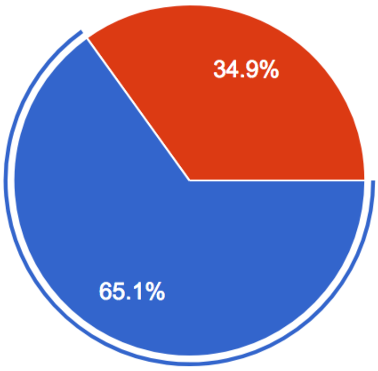


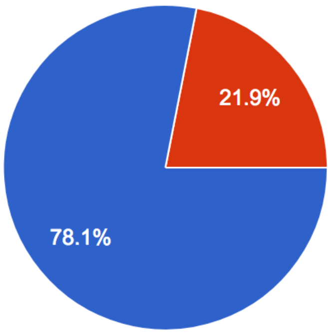
12.4 Students discuss the distribution of different species by the planet. They collect existing information and propose strategies for the preservation of endangered species.



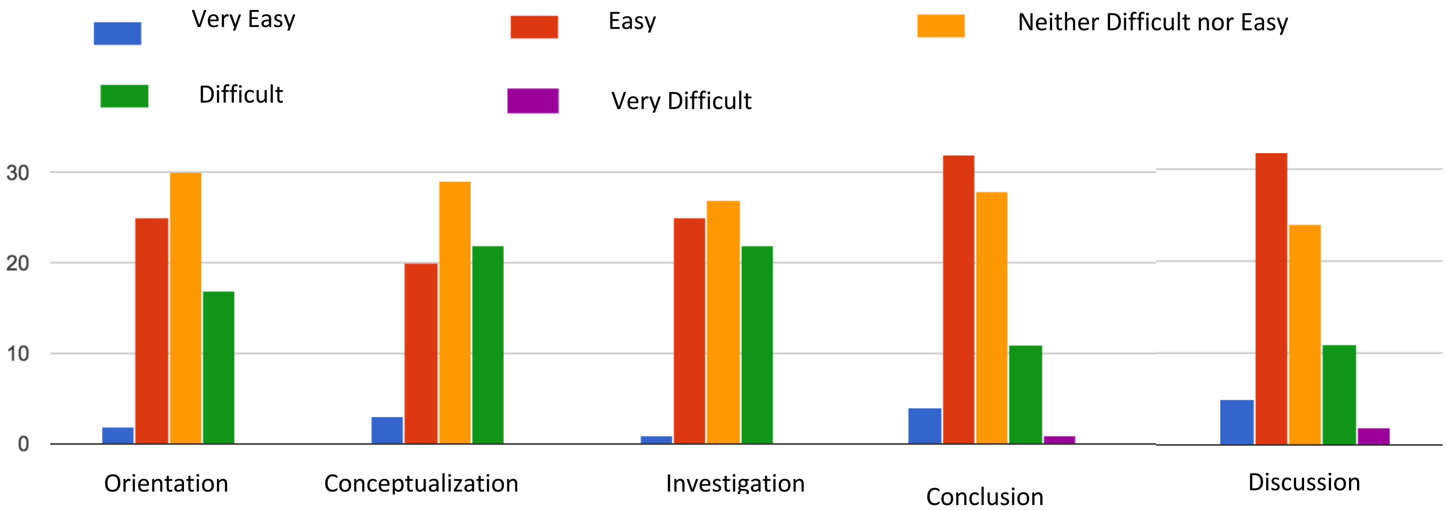


12.5 Students, in groups, do a detailed research on the benefits of space exploration and present the results to the other classmates during a discussion session on the importance of space exploration in our lives.



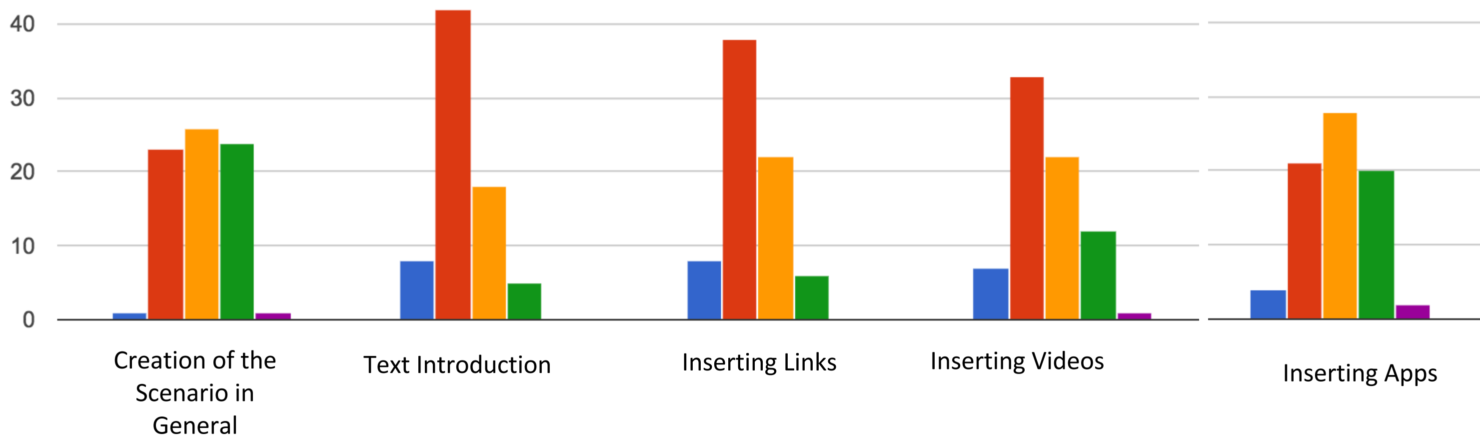


13. Indicate the degree of difficulty experienced during the design of the following stages of the IBL scenario you created:

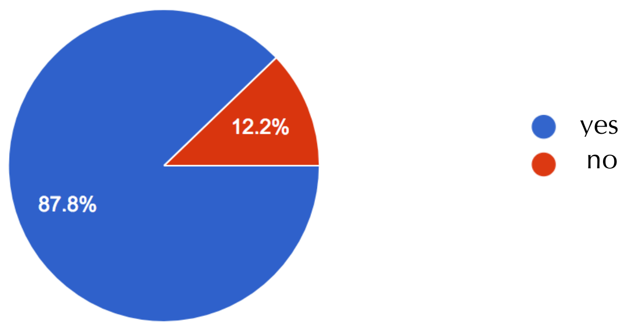


One person found it very difficult to prepare the conclusion phase and 2 the discussion phase

14. Use of the platform for creating IBL scenarios (Graasp / Go-Lab)



15. Do you intend to implement the scenario you created in your teaching practice?



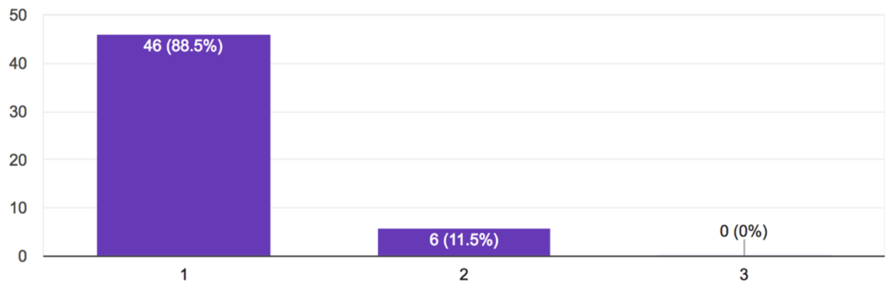
Those that answered no:

- My planification for next year is ready
- Not appropriate for 3rd cycle
- Not appropriate for my teaching area
- Don't see any pedagogical value
- Because I didn't use in the best way
- It requires linguistic proficiency and time consuming
- Not appropriate for my area but I will use IBL
- Not easy to use ICT in my classes

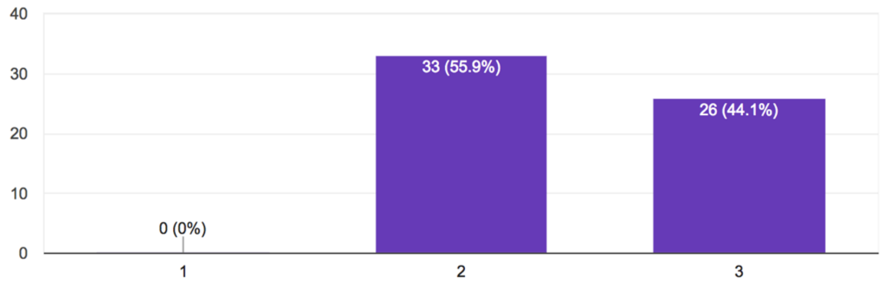
Bachelor in Science Education Student's Answers (Pre – 53 responses, Post – 62 responses)

5. How do you characterize your degree of knowledge of the concept Inquiry based Learning (IBL)

Pre Training Questionnaire



Post Training Questionnaire



6. In which context you had contact with the IBL methodology

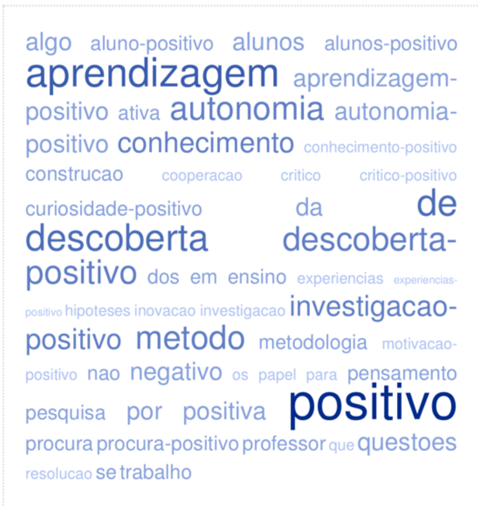
Pre Training Questionnaire

None prior experience by most of the participants that answered this question on the questionnaire and the participation in this course was the first encounter.

7. Indicate five terms / words that associate the IBL and indicate if it is something positive or negative ahead of each of them.

Pre Training Questionnaire

Post Training Questionnaire



9. 1. If in your school journey you encountered an instance of IBL please refer a positive aspect of it:

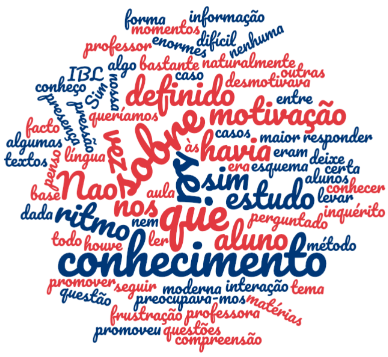
Pre-Training

Post-Training

9.4 Did the use of IBL promoted motivation for learning?

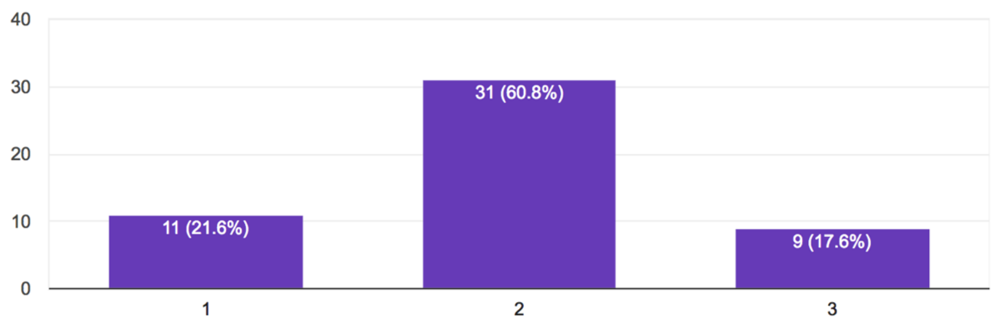
Pre-questionnaire

Post-questionnaire

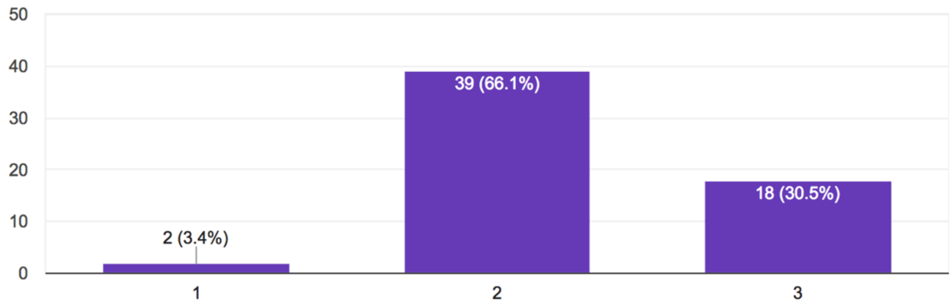


10. How do you characterize your degree of knowledge of ICT resources for educational purposes

Pre-Training Questionnaire

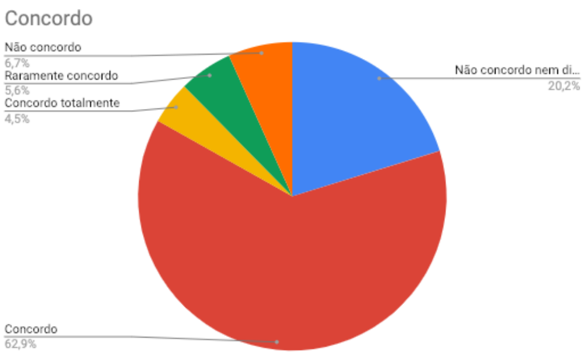


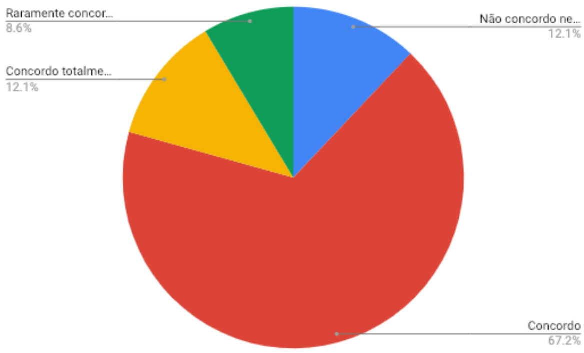
Post Training Questionnaire



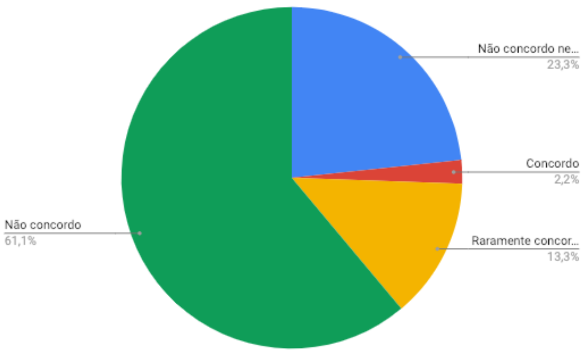
12. Please indicate your level of agreement with the following statements, considering the scale presented.

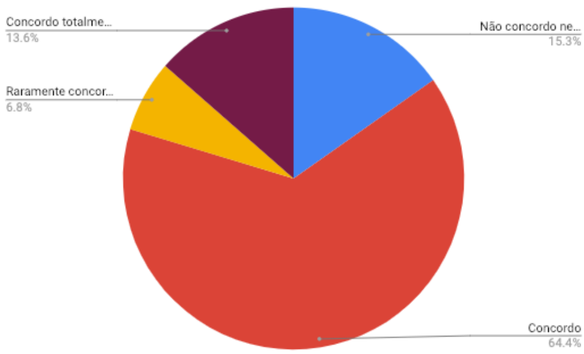
12.1 I have experience of using ICT in education.



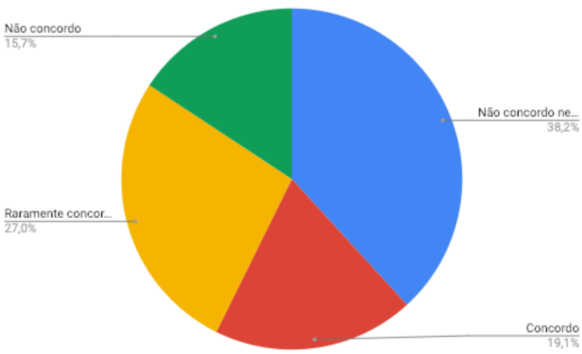


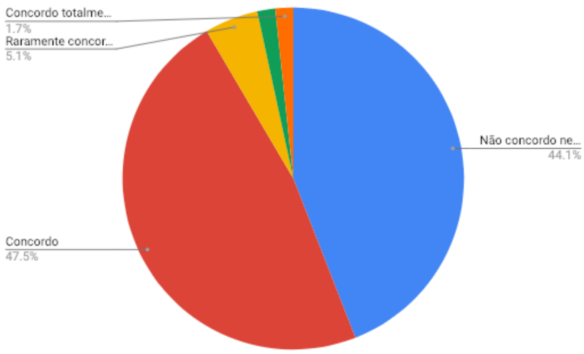
12.2.I have IBL knowledge that allows me to use it in the planning and implementation of educational activities.



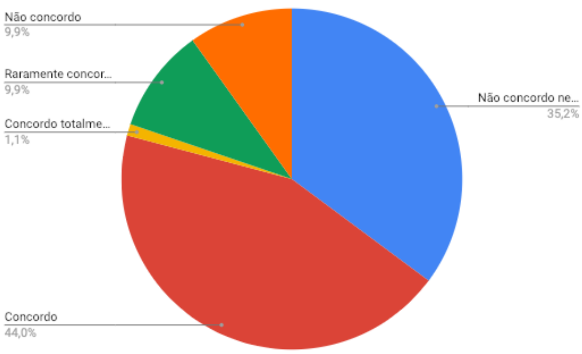


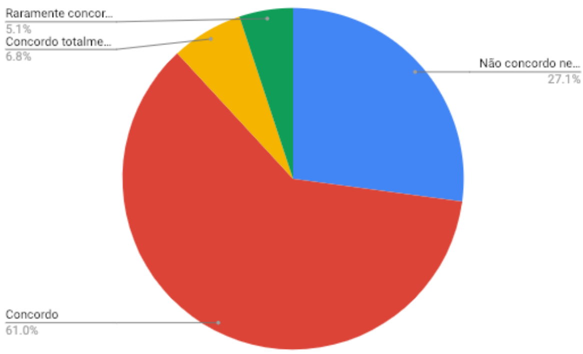
12.3. I know how to evaluate educational activities that use the IBL methodology.



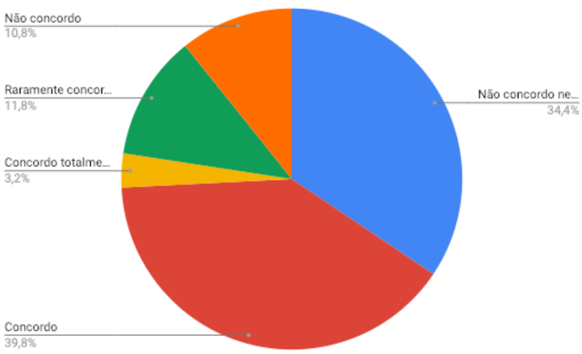


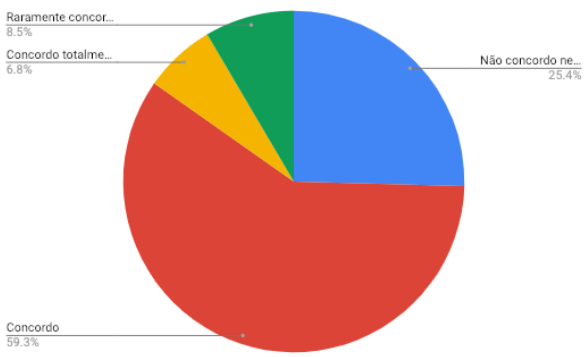
12.4.I have knowledge of various educational strategies



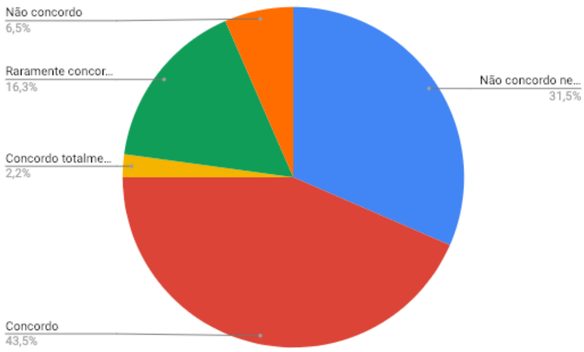


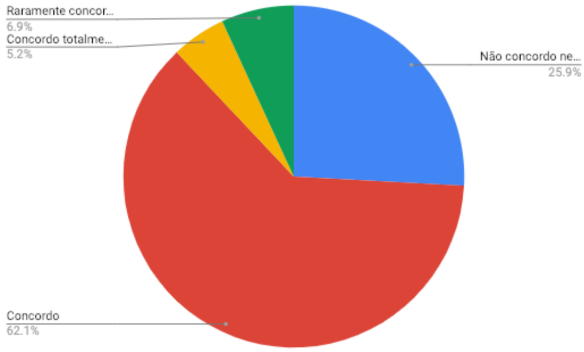
12.5. I know how to select effective educational approaches to promote active student involvement and cooperative learning.



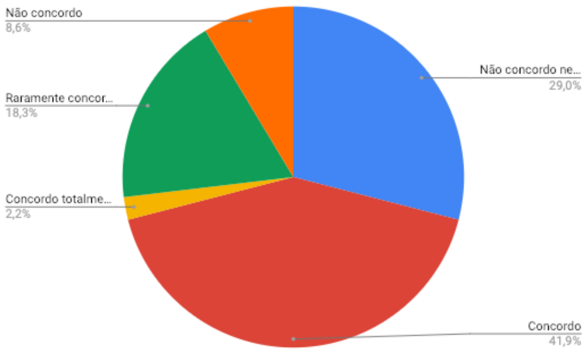


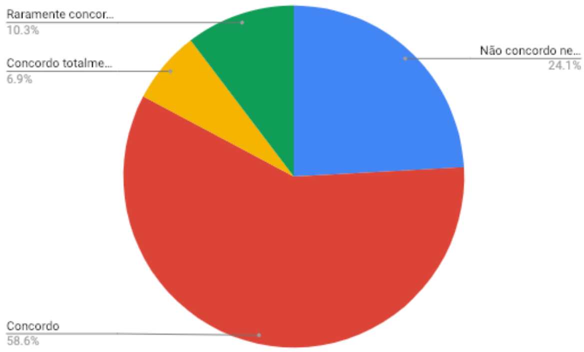
12.6.I am able to adapt strategies to different educational activities.



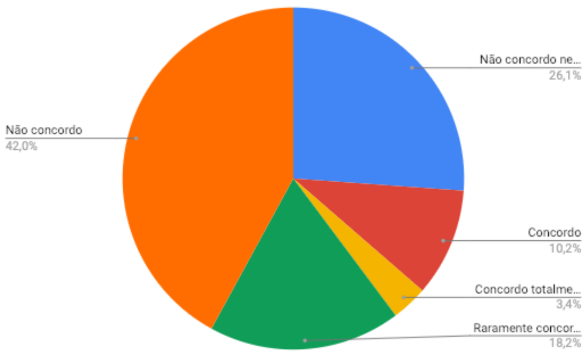


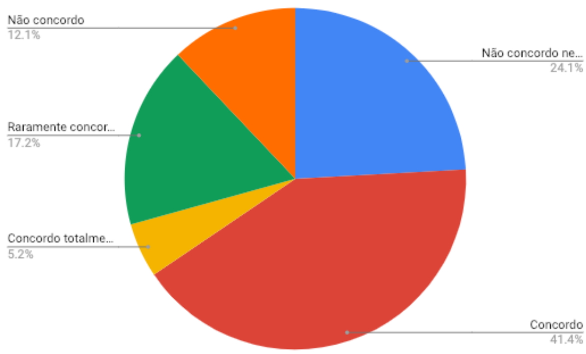
12.7 I know how to choose technological resources that evidence the contents.



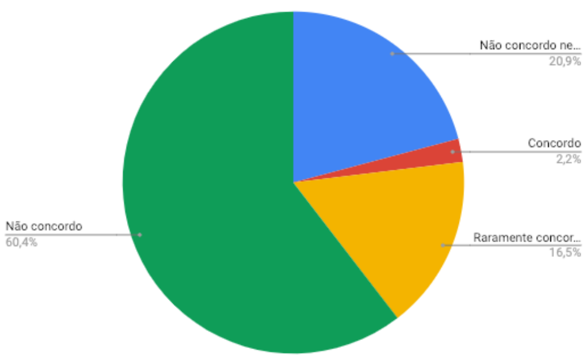


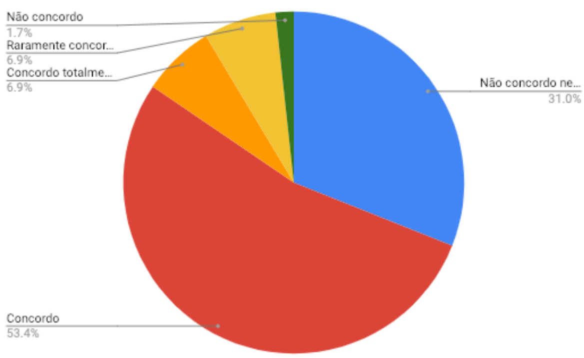
12.8.I have participated in training activities related to educational strategies.





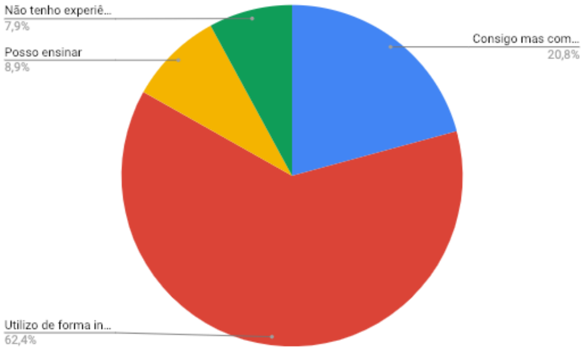
12.9.I have experience in planning activities involving IBL and ICT

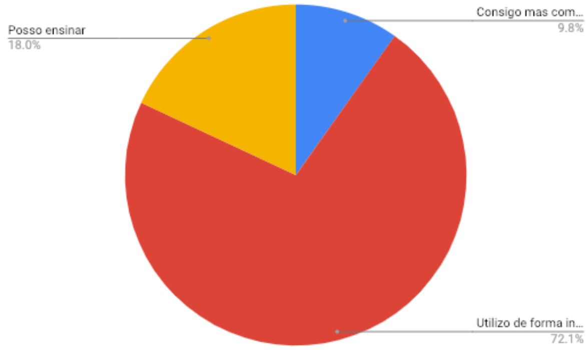




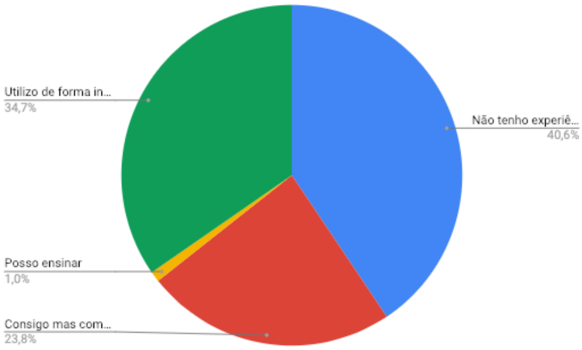
13. How do you characterize your degree of involvement with ICT?

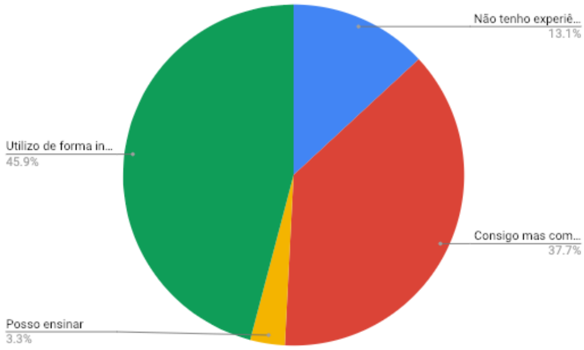
13.1 Using digital tools.



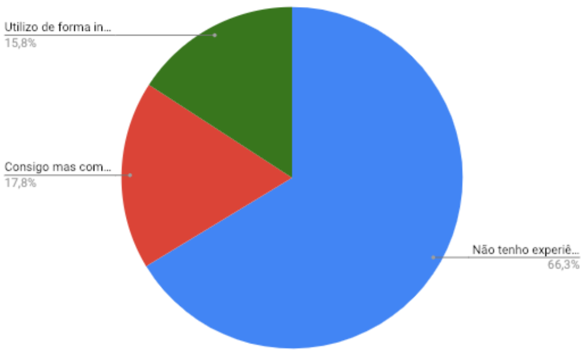


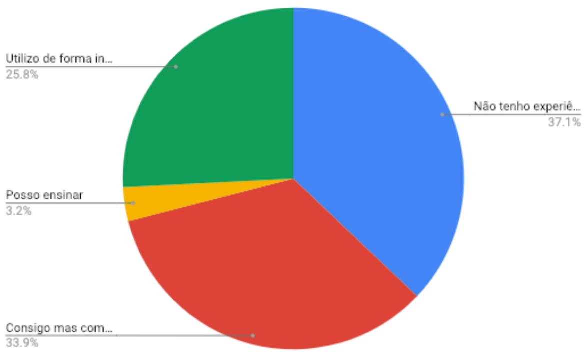
13.2. Use of educational material repositories.



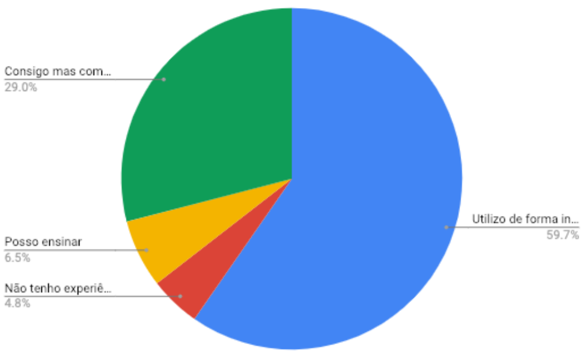


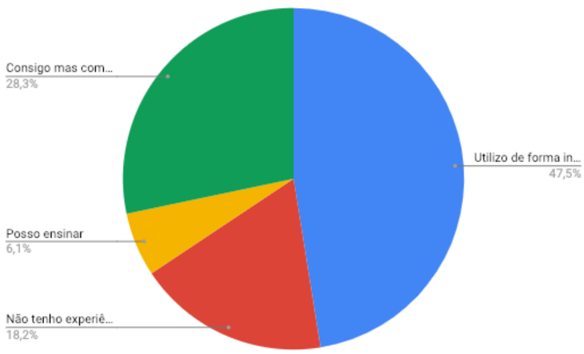
13.3. Use of laboratories and virtual simulations.





13.4.I appreciate exploring new tools and technologies.

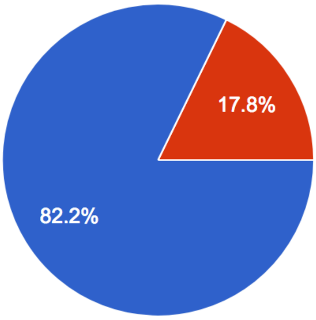


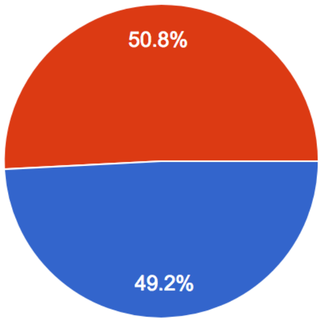


14. Please indicate which scenarios represent an inquiry learning activity.

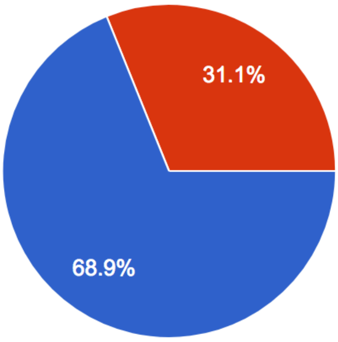
Pre Training Questionnaire | yes | no | Post Training Questionnaire

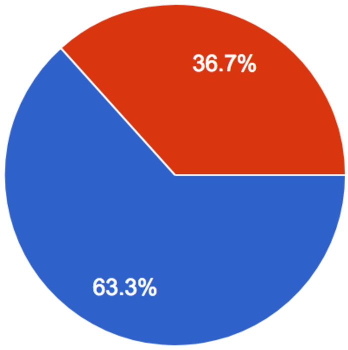
Students follow a protocol to develop an activity.



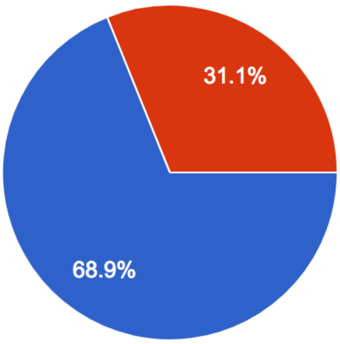


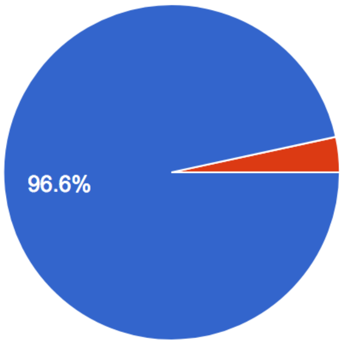
Students use an existing chart to explain how average temperatures vary along one year.



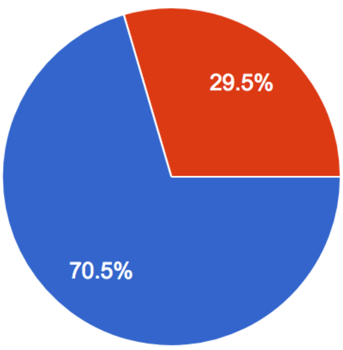


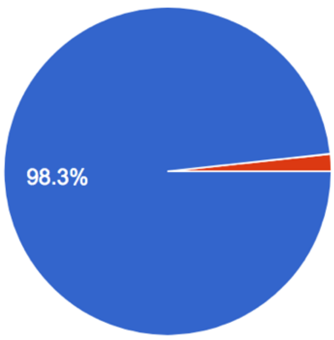
Students discuss the relation of temperatures and solar activity



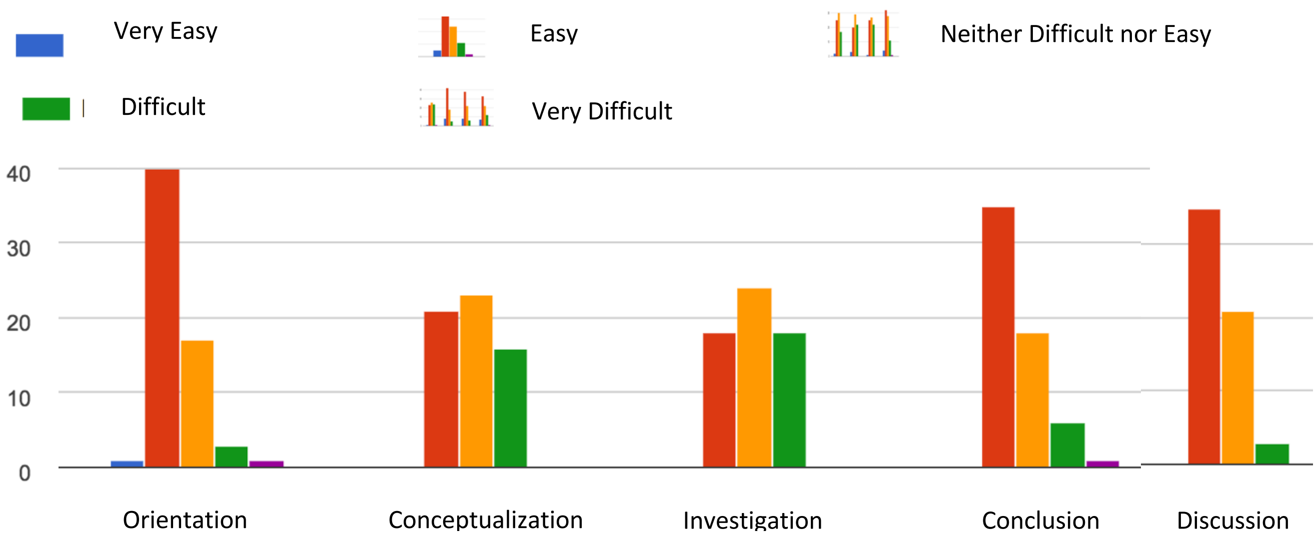


Students discuss the distribution of different species by the planet.

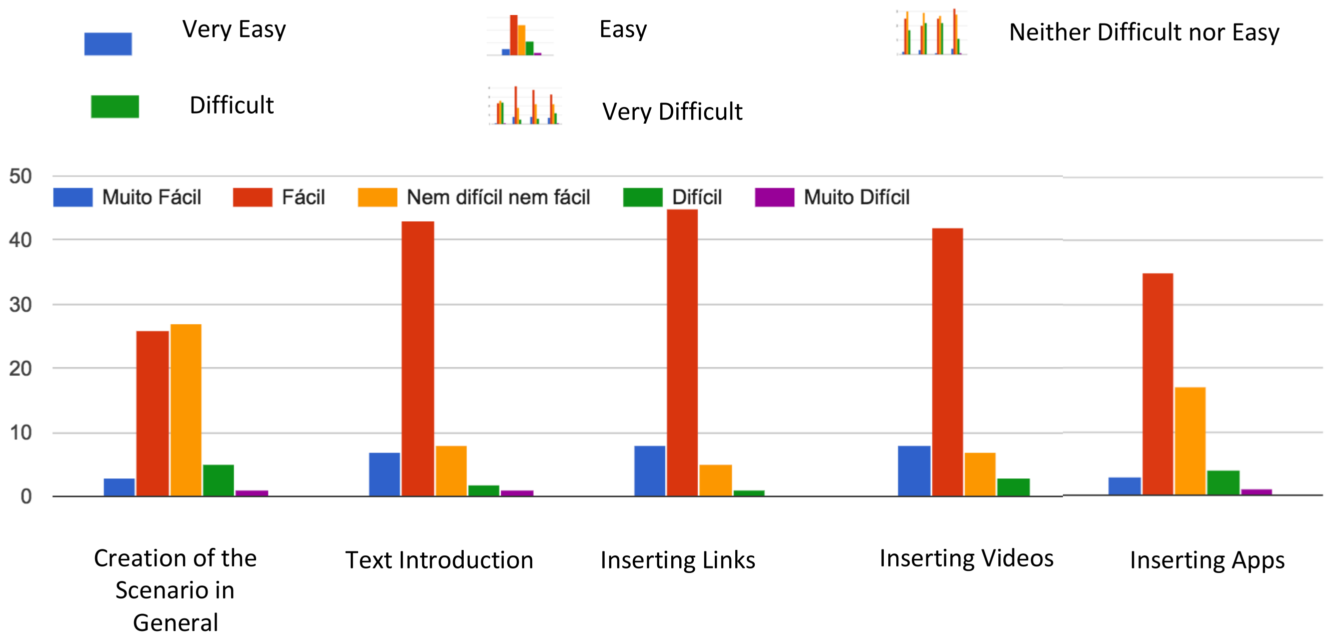




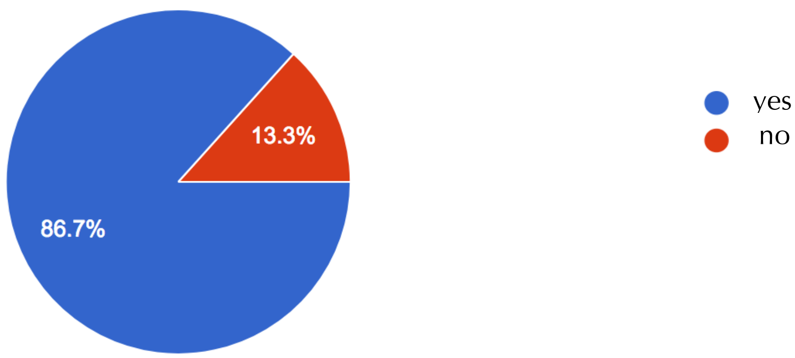
13. Indicate the degree of difficulty experienced during the design of the following stages of the IBL scenario you created:



14. Use of the platform for creating IBL scenarios (Graasp / Go-Lab)



15. Do you intend to implement the scenario you created in your teaching practice?



Those that answered negatively had the following explanations:

- Because I will not work in the field of training
- I am not employed yet.
- The ILS was properly elaborated, and I feel it is possible to apply but I am not confident in my competencies to do it.
- Although I invested a lot of time in the creation of the ILS I think I still would have to improve it a lot before using it in my professional activity. In particular to ensure I would not guide the students more than necessary.
- I don't think I have the necessary qualification and don't intend to work with this. But I would recommend to other people

19. Based on your experience what suggestions would you give in order to improve the use of the platform? Below the most common suggestions:

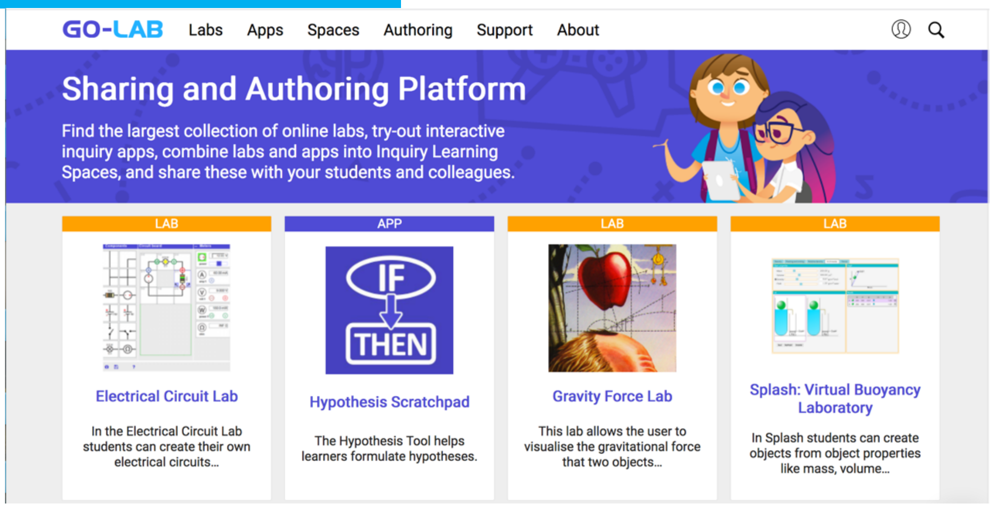
- Have smaller groups when introducing the platform and have a specific session only for the use of the platform,
- Provide support to each group of students individually,
- The platform is addressing only STEM teachers. It would be nice if it could be applied to other subject areas.
- Not very intuitive,

20. What were the most positive aspects of your experience with IBL?

- To get to know new content,
- I acquired new knowledge to which I have not been exposed during school,
- It is an innovative method that, when properly organized, bring several positive aspect and foster academic qualities among others,
- It is interactive,
- Learn to be autonomous,
- Contributes to the self-learning process and develop competencies such as autonomy, critical thinking, among other important ones,
- Self-development through research and reflection,
- The contact with IBL and knowing that it can be used at a professional level was very rewarding. I think the involvement in the discovery and research makes learning more significative,
- It didn't bring negative aspects,
- The ease to use and innovative aspects are two important positive aspects.

Appendix VII Brief Introduction to Go-Lab Manual

Go-Lab



My name is Go-Lab, nice to meet you!!

Table of Contents

Introduction

This document intends to be a companion to the organization of a Go-Lab Introduction Workshop. It outlines all the basic components that need to be addressed while introducing beginners to the whole ecosystem of the project. This document also presents a few important tips and tricks on how to organize teacher training workshops in general, how to create a nice atmosphere where everyone is willing to learn and share their experiences. Remember that the first impression, the first moments of a training event will set the tone of the full experience. The document slowly navigates from the teacher's needs towards what Go-Lab can offer to improve their daily experience as educators and facilitators of learning. The various components of the portal and authoring tool are briefly presented and a short introduction to Inquiry Based Learning integrates this document. Tips for a successful practical session are distributed throughout the document and some concrete examples will help trainers and educators take the first steps towards a smooth navigation in the project and foster the future use of Go-Lab as a best travel companion.

Ice Breaker

Meet and Greet

Introducing a new project to a new audience might be a challenging task, the creation of a proper atmosphere will make the achievement of the mission much easier. An "Ice Breaker" can be any activity that will induce the participants to feel more comfortable and relaxed, to be open to absorb the new learning and opportunities that are about to be presented to them and to feel integrated in a friendly environment where they are not being tested or evaluated. Give the participants their moment of fame where they will be able to share their experiences, their preferences and fears. Make sure you also take part in whichever activity you promote so that you don't place yourself in separate group. For participants to absorb the new content and challenges you are about to show them it is important for them to start in a "place" where they feel comfortable. In other words, make sure you find where is the starting point of each participant, that stage where they feel comfortable in their daily teaching/learning practice and start from there, wherever this place is. Remember, you must ensure that everyone feels that what they already know is good enough and that they will have all necessary support to take the path you are presenting to them. Make sure you make them comfortable enough to ask questions, share worries and opportunities and above all that they feel part of the process and not just listeners of ready-made solutions.

Ice Breaker are activities where you welcome the participants and make participants feel comfortable to interact with each other. You can for instance group the participants randomly and ask them to find out something about the other people in their group: something that they really like, something that they hate, etc. Or for instance have them share what was the most outrageous thing they did in their lives or which is the moment they will cherish forever. Ice-breakers are not meant to retrieve useful information, they are built to ensure that the participants feel comfortable with each other and with the organizers.

Meet and Greet is another important part of a successful event. This is the moment where you get to know more about your audience, they get to know more about each other and about the organizers. After the ice-break (which can also be part of the meet and great) participants will be in a better mood and feeling more confident to share a little bit about themselves. Have them share with the audience where they are from, what they teach, what are their expectations for the specific training, etc. Be creative and adapt these ideas to your community.

Here are some ideas for the Meet and Greet activity:

- Ask participants what their favourite topic is to share with the students,
- Discuss about their favourite methodologies in classroom,
- Discuss which are the favourite tools and resources they use in their daily lessons,
- Ask them to share with everyone a lesson that went really well and one that didn't work at all
- Promote a discussion about the trends, obstacles and opportunities in their school/region/country, etc.

Make sure you are also part of this process. Participate in the activities just like everybody else. This will make it clear to the participants that you are not putting yourself in a position of someone that knows more than the rest of them. Make sure you form a team and make everyone ready to learn, share and have a good time.

Go-Lab Project in a Nutshell

Now is the time to present Go-Lab, probably the reason your audience is there with you. Start by giving them an overview of who are the people behind the scene. Show some numbers and where are the coordinators and ambassadors around the world. Presenting who are the main developers in terms of technology, pedagogical model and community building will make them feel safe and will count as a plus when they have to start with their hands on Go-Lab and the initial challenges while overcoming the learning curve. Show them that Go-Lab is being used all around the globe (Figure 140).

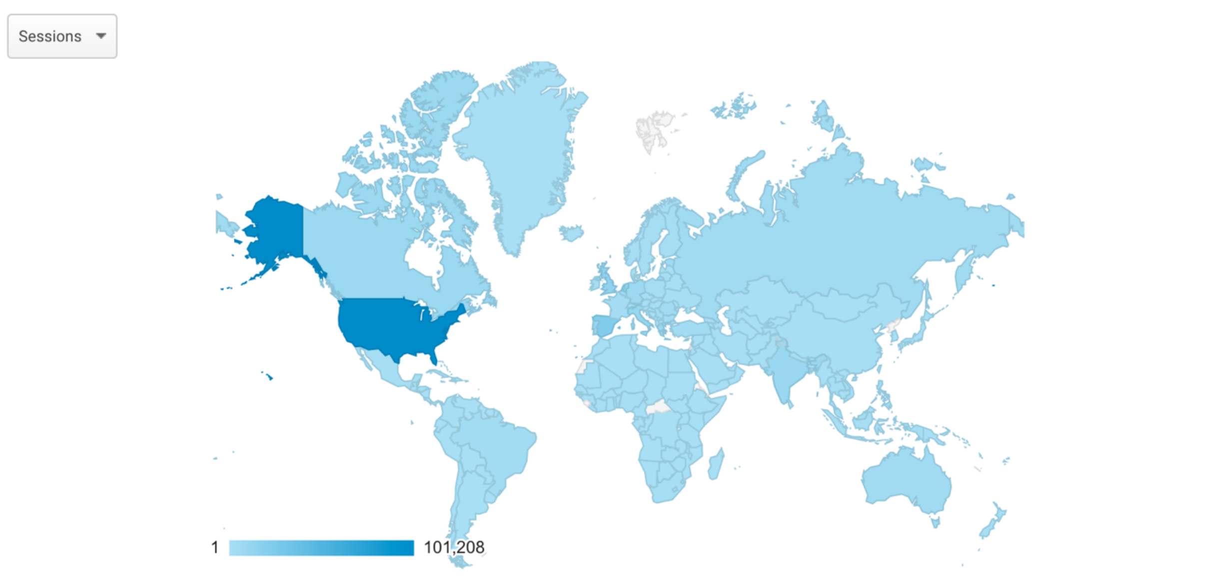


Figure 140 Graph with the representation of the use of Go-Lab around the world (Dec. 2017) - 200 thousand users from 190 countries worldwide

Show them the statistics in your country and how the project can be well adapted to the current practices for science education.

Ingredients for a good lesson

Next step is to prepare the strategy to show them how Go-Lab can be useful for them. One of the common trends nowadays is that teachers will gather lots of different types of tools and resources in order to make their lessons more meaningful to the students and to help them shift the focus to the student learning instead of teacher's delivery of content.

Remember: You are starting to present to your audience an innovative solution for the introduction of Inquiry Based Learning (IBL) methodology in classroom. Use IBL while you are working with them during the training sessions as they will have to use with their students. Don't tell them how useful Go-Lab can be, make them find out for themselves. Start by asking a few questions to trigger their interest, for instance:

- What are the main goals?
- What are the must have ingredients?
- What are the type of tools and resources assembled for the different lessons?

If you have enough time, you can ask them to write all in post-its and assemble all their answers together in a wall, grouping them under different categories. If you want a more ecological version, you can use digital post-its (i.e.: PADLET – http://padlet.com). Now ask them how they use this set of materials and strategies to create engaging lessons. In this part you are using IBL yourself by helping them set the scene and retrieve prior knowledge, the orientation part. Remind them that it is very important to spark the interest of the student for the topic they are about to deliver. Suggest a few strategies to achieve this, have them share ideas. This is important in particular if your audience is not very acquainted to the IBL methodology. After finishing this part, you will probably have already a collection of tools and ideas to assess the student's progression. It is a good time to discuss the different solutions available. If this topic didn't emerge before then you have a good excuse to introduce your audience to the 21st century skills. You can take the opportunity to review your education authorities' position on this and suggest alternative solutions. You can find a good reference for the pillars of 21st century skills here:

http://www3.weforum.org/docs/WEF_New_Vision_for_Education.pdf.
After this you are ready to present them the Go-Lab authoring tool. Not the portal yet, wait a bit more.

Meet Go-Lab's authoring tool – GRAASP

Before going to the portal there is one last stop, to show them what is it like to be a student using the platform. This will make it easier for them to understand the different parts that are integrated in the same lesson and if they are not IBL frequent users, understand better the difference between traditional teaching and the Go-Lab proposed pedagogical model.
To build trust on what you are about to present, show them some statistics of the use of the authoring tool. This will boost their confidence on GRAASP (Figure 141).

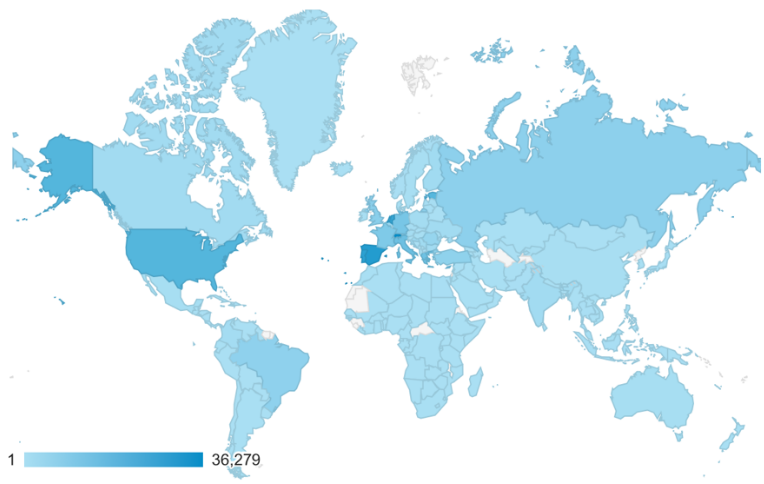


Figure 141 Graph with the representation of the use of the authoring tool around the world (Dec. 2017) - 19 thousand teachers registered and almost 10 thousand ILS created.

After presenting some analytics of the authoring tool and ILS creation tools you should choose the lesson that is more appropriate to the audience of teachers you have in your session and present it to them as if they were students. Select one that will aggregate all the major features of Go-Lab such as: multiple apps, one or more online lab, assessment tools, videos, documents, etc. Make sure it is a short lesson that will give them an overview of the possibilities of the platform but that will also enable you to present, after the exercise is finished, what can the teacher see in the authoring space. Discuss about safety of the information provided and the importance of having "Learning Analytics" enabled if they want to retrieve information about what the students are doing.

Exploring Go-Lab Portal

All the introductory steps above prepared the teachers for their first encounter with the Portal. They will now understand much better how the system works. Now is time to present the portal, its multiple offers and from there move to the creation of their own Inquiry Learning Scenarios (ILSs). Give them some time to navigate the space and get to know the multitude of Online Labs, Apps and Spaces. After some free time to explore the different parts of the Go-Lab portal(Figure 142), ask them to choose a lab and show them how to preview it and how to create an ILS starting from this selection.

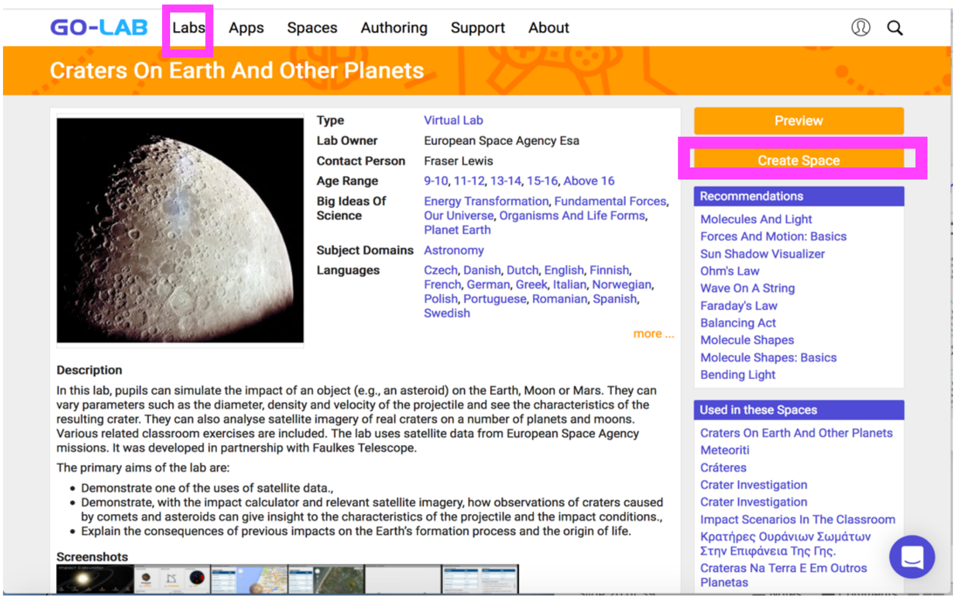


Figure 142 Print screen of Go-Lab portal featuring the Labs option

Show them on Graasp how the lesson will look like from the point of view of the students and of the teacher. Next you can explore the same procedure but this time starting from an existing ILS, either proposed in the specific Lab page or by searching directly in the ILSs menu. The preferable choice is to use one ILS mentioned in the specific Lab page so you can show the difference existing when we create an ILS from the Lab or just copy an existing ILS. Show them that in this last case all the spaces are filled with content and they can immediately use the ILS or change whatever they may wish in order to fulfil their own teaching goals.
Ask them to select one ILS, copy it and start exploring the different possibilities. Make sure they understand that what they have now is a copy of an existing ILS but this one is only theirs for their private use. The changes they will introduce, and the data of their students are only available to the user who made the copy.

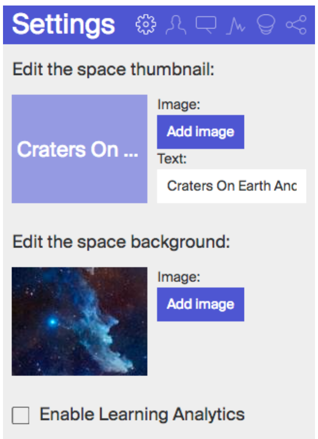


Figure 143 Print screen of Graasp featuring the option for enabling learning analytics

Present to them the sharing possibilities and how they can collaborate with their colleagues within the same lesson. The link for the student is the "Stand Alone View", a unique link that will not change during the lifetime of the ILS. It is now also a good time to introduce them the Go-Lab learning analytics tool (Figure 143). If they want to be able to track what their students are doing, they will have to enable this function. Also alert them not to delete the VAULT or some of the apps might stop working as well as some retrieval of data. Give participants now some time to digest all the information and play a bit with the lesson they have copied. Ask them to introduce changes, insert videos, links to other tools, etc. If there is still time you can now move to the last part which is to invite them to create an ILS from scratch. Explain that there are different IBL models and suggest for beginners the use of the basic scenario.

Assessment Tools and 21st century skills

Go-Lab is a very good companion of teachers that are willing to engage in the assessment of 21st century skills. There are several apps that can support the acquisition of relevant information to support the assessment of the progression of students in terms of their own competence profile. There are several types of tools:

Tools that can help teachers to be aware of how the students have used the ILS. Tools to support student's own reflection (Figure 144):

Progress Bar

Figure 144 Example of self reflecction tool

Tools that can support the one-to-one interaction of teachers with their students as for instance the input box and the teacher feedback tool (Figure 145):

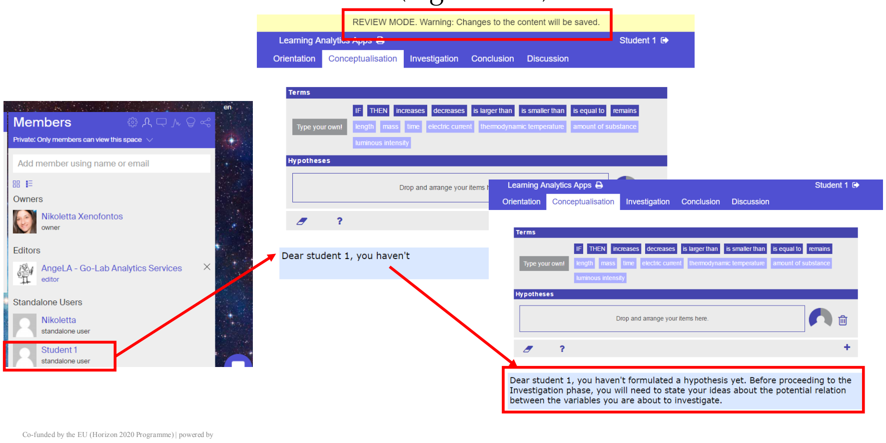


Figure 145 An example of an input box

Tips for Inquiry Based Learning

Finally make sure that participants have a basic understanding of what is Inquiry Based Learning. A good way to ensure they understand it is to start discussing the scientific method. Ask participants what the steps of the scientific method are and you will end up with a diagram similar to this one (Figure 146):

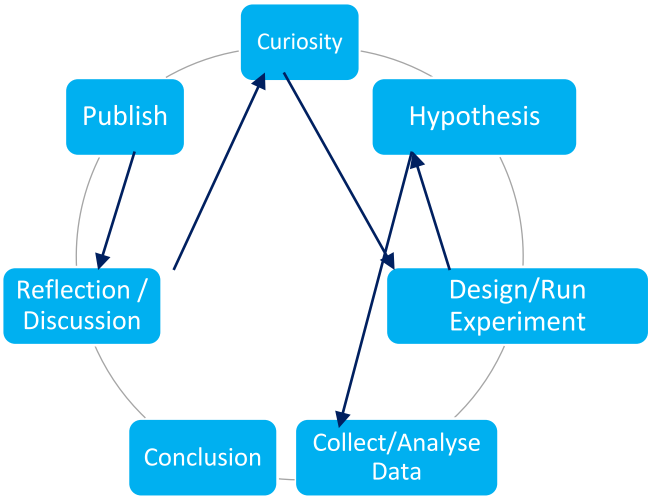


Figure 146 An example of possible sequences when applying the scientific method

Following this discussion, you just need to explain that if you help students follow this strategy in classroom while learning new concepts and acquiring new skills, they are using the IBL methodology.

You can now introduce the Go-Lab inquiry cycle (Figure 147):

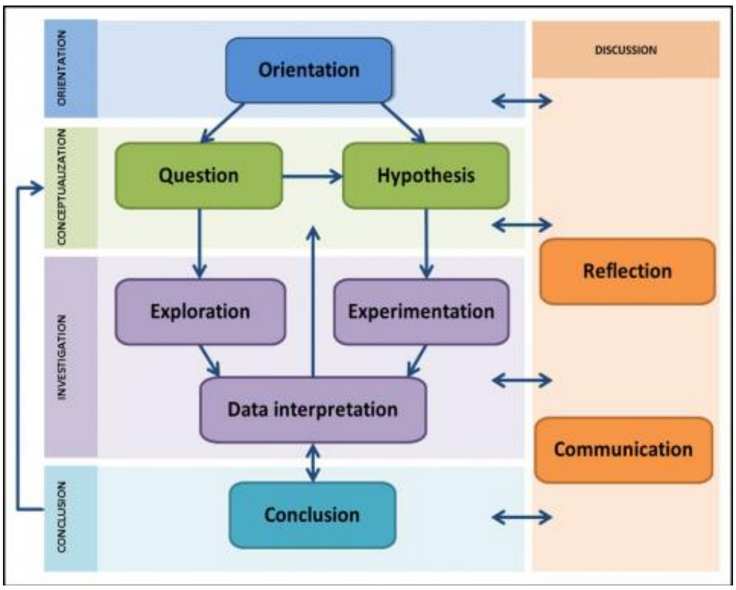


Figure 147 Go-Lab Inquiry Cycle

You can briefly refer that Inquiry can be a very structured process or follow a more guided approach or even act as an open-ended research trigger. For educators that are well accustomed to the traditional method, this might be very disconcerting. You can bring them back to their comfort zone by stating that there are different types of Inquiry starting from very structured models to open ended queries. There are different definitions of the different existing types but in essence what matters is the degree of freedom given to the student and how many variables they can manipulate. Alert them that students might also react against having so

much freedom to choose the way they will build their learning experience. The use of IBL is a step by step process that should be slowly adopted. But once the mindset is shifted it will be very difficult to go back to the traditional view of content delivery and learning experiences. A good introduction to IBL can be found here: [Inquiry under the Microscope]
And a nice activity to introduce students to the scientific method can also be found here:
[Mystery Boxes]

By following the existing Inquiry Learning Spaces of Go-Lab you will be able to see how the different authors are building their lessons using this methodology. There are many spaces covering several subject domains. You might also, depending on the level of acceptance of the inquiry methodology, introduce them to the different existing scenarios, available when users start the creation of their ILSs.

Go-Lab Support Page

Finally, it is important to tell your participants that you don't expect them to remember everything you shared neither to feel comfortable with all the innovative aspects you have shared. This session is foreseen to have a minimum of 6 hours' duration and to serve as an appetizer for further training opportunities. Suggest to participants to start with small and simple things and from there move to a more complex employment of the platform and its multiple possibilities. Show them the support page where they can find multiple materials to help them navigate the possibilities of the portal and its authoring tool and also show them Intercom, the online support facility being used by Go-Lab.

Wrap-up

At the end of the session you can do a fun evaluation of the session and at the same time introduce them to a tool that enables interactive evaluation sessions. For example, you can use Mentimeter (https://www.mentimeter.com/) to create world clouds (Figure 148):

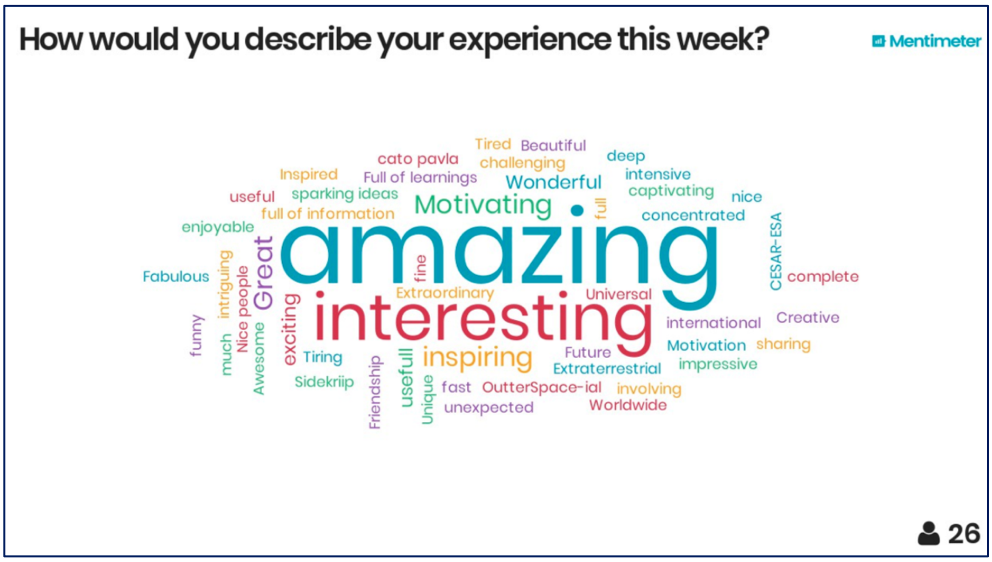


Figure 148 Example of a mentimeter word cloud

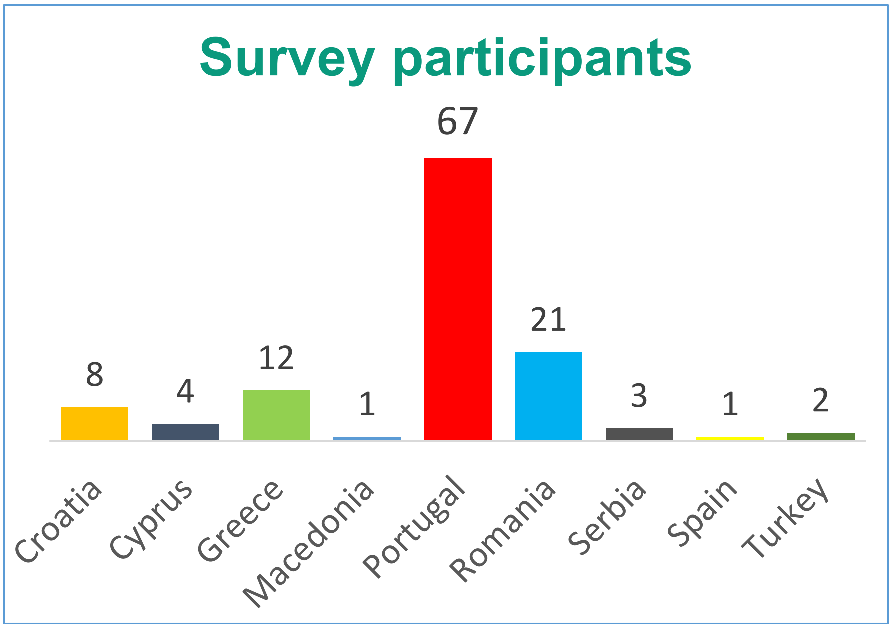
Review the path taken during the training event and show them that you have used the IBL model to introduce them to Go-Lab. Make sure you provide certificates for their attendance, if they agree promote an exchange of contacts and ensure they feel confident and supported to continue the Go-Lab adventure with you.

The Training in a Nutshell

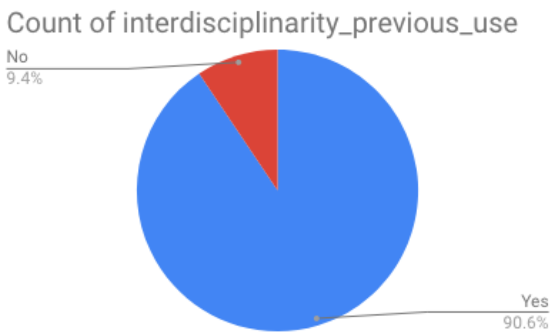
- Start the training with a brief introduction of everyone involved and with a nice ice-breaking activity, the more comfortable the participants feel with each other the more likely they are to participate actively in the training,
- Trainers and trainees are professionals with equal level of knowledge in their own field, the training opportunity is a sharing of best practices and experiences. Be open to learn from the participants as well,
- Ensure there is enough space in the training for the participants to take the stage whenever they feel they have something to share with the remainder of the group, including the trainers,
- Ensure that the specific needs of your audience are met. As it happens with students in a classroom, everyone has special needs. Meet each participant in their comfort zone,
- If you need to introduce components using the expositive way, make sure a series of hands-on activities are mixed in between the expositive moments,
- Whenever possible try to accredit the course with the local education authorities, this might be very important, in particular when accredited courses are a requirement for the progression of your participant's careers,
- Recognize the participation of the teachers delivering a nice attendance certificate with the signature of the organizers of the course and any other relevant endorsement you might need, teachers are usually very proud to see their achievements in the form of a meaningful certificate,
- Introduce a coffee break or a meal every 2 hours. Ensure that you have something for your participants to eat and drink on demand. Remember, our brain is an energy killer. If you have the necessary funding offer this and other goodies, who doesn't like it?,
- Ensure the environment were the training is taking place is comfortable and collaboration friendly,
- Provide participants with enough time to meet each other and to talk to each other,
- Include in your training as many energizes as necessary, as your participants to bring their own ideas, they are very good to keep the moral of the team,
- Don't forget to evaluation the course and give the floor to the participants to express their sincere view of the training course and its value to them, make sure the replies can be done in an anonymous way,
- Ask your participants permission to take their pictures and to use their emails to send future information,
- Before you finish the training make sure they have your contact or from a member of the team that can provide future support.

Appendix VIII PLATON Survey

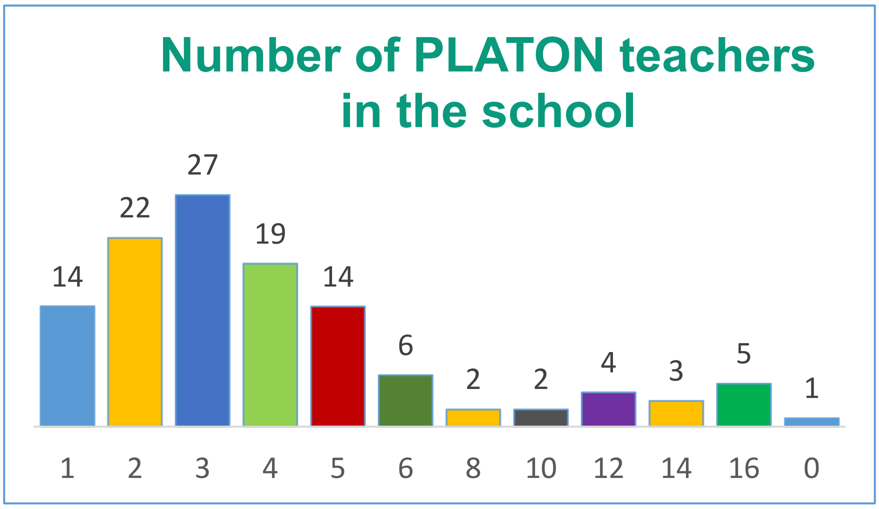
(138 teachers started to reply the questionnaire but only 119 replies reached the end. The questions where not mandatory)



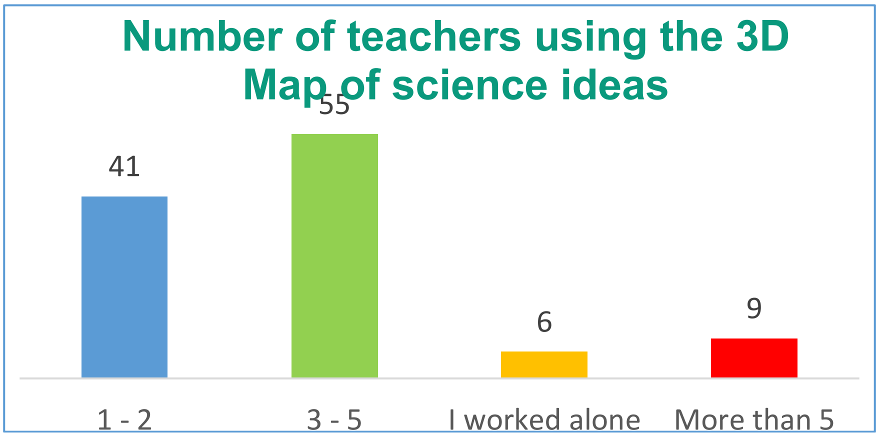
Have used interdisciplinarity before?

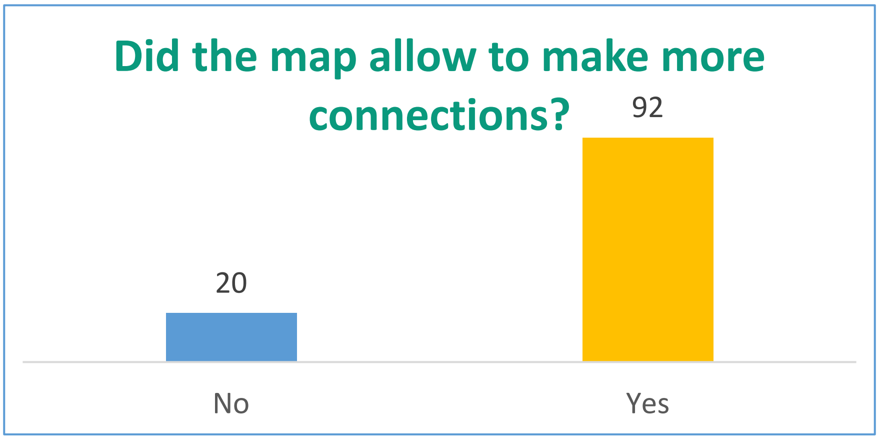


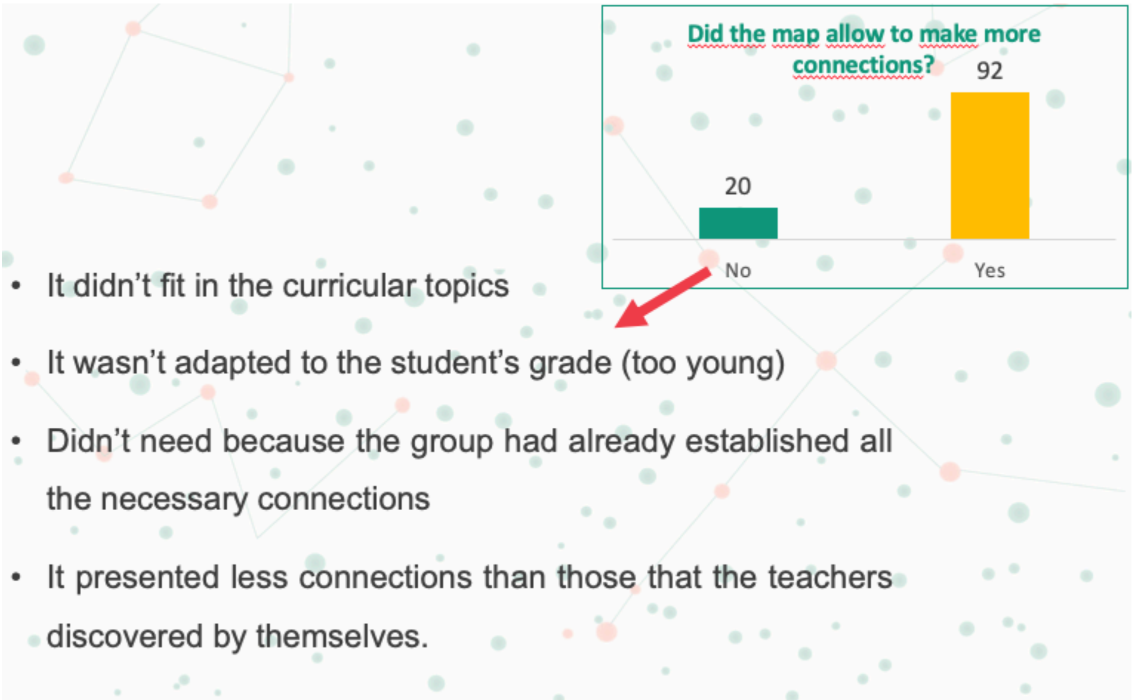
Have used inquiry before?

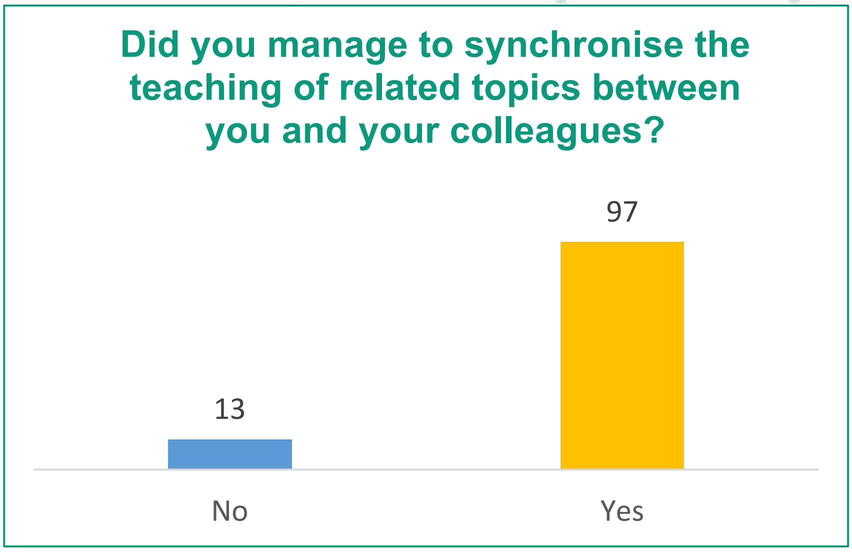


Main fields involved: Physics, Astronomy, Geology, Geography, Maths, Biology, Chemistry and environmental sciences.

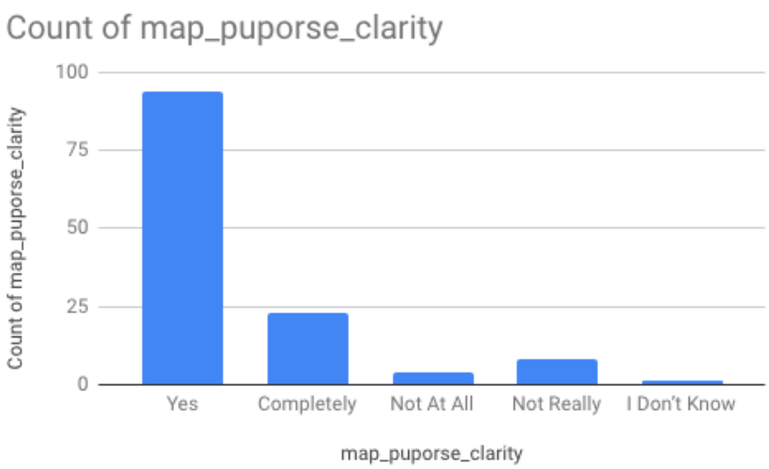




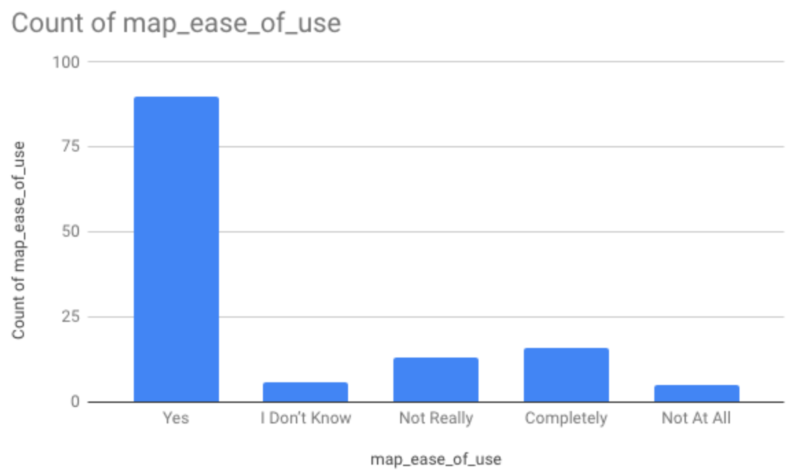




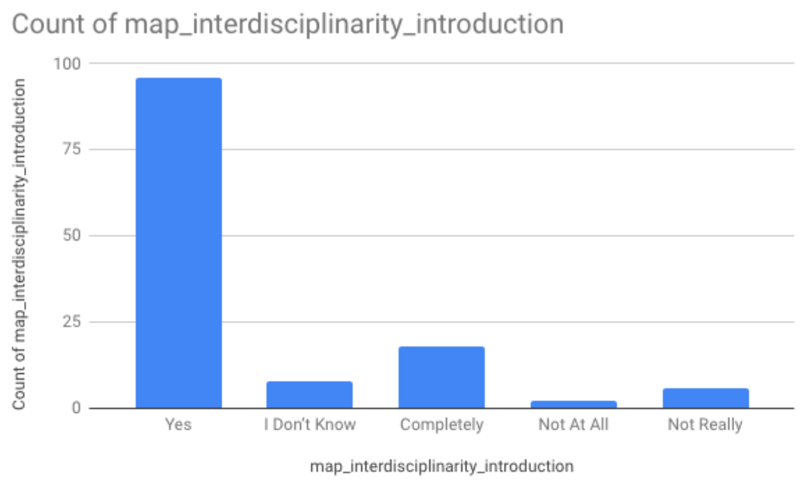
Is the purpose of the 3D map clear to you?

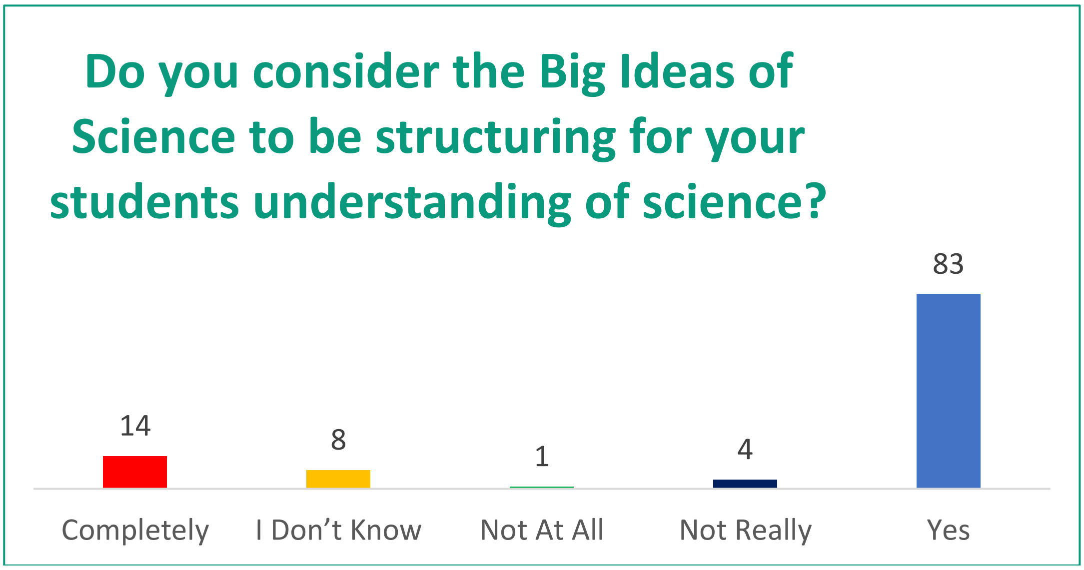


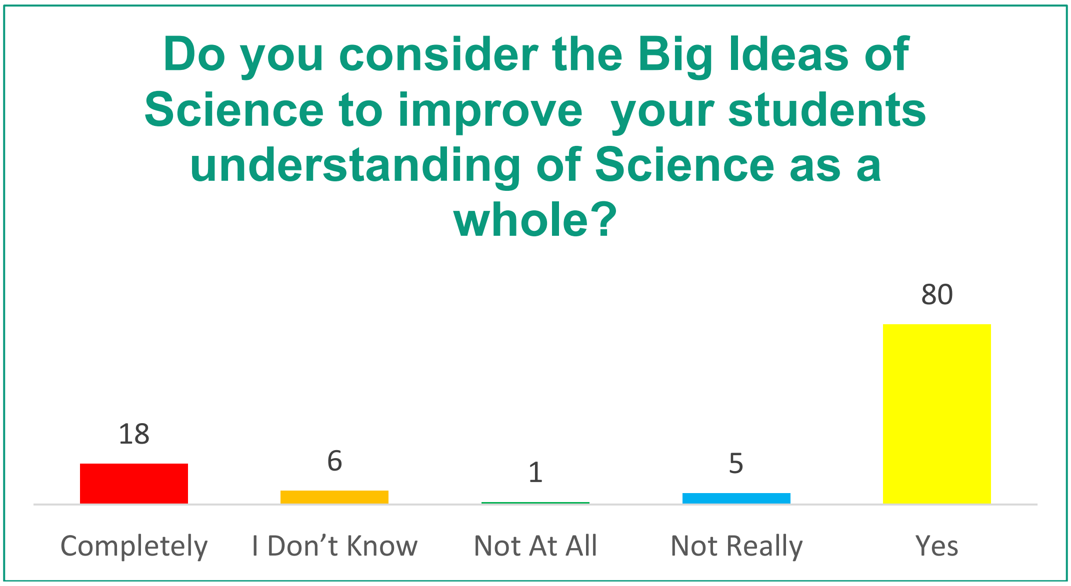
Was the 3D map easy to use?

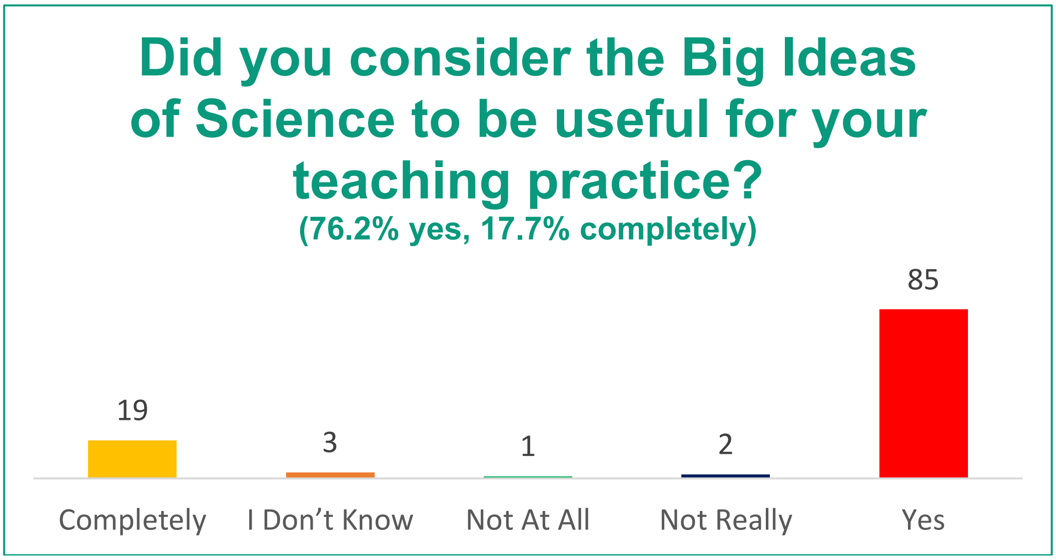


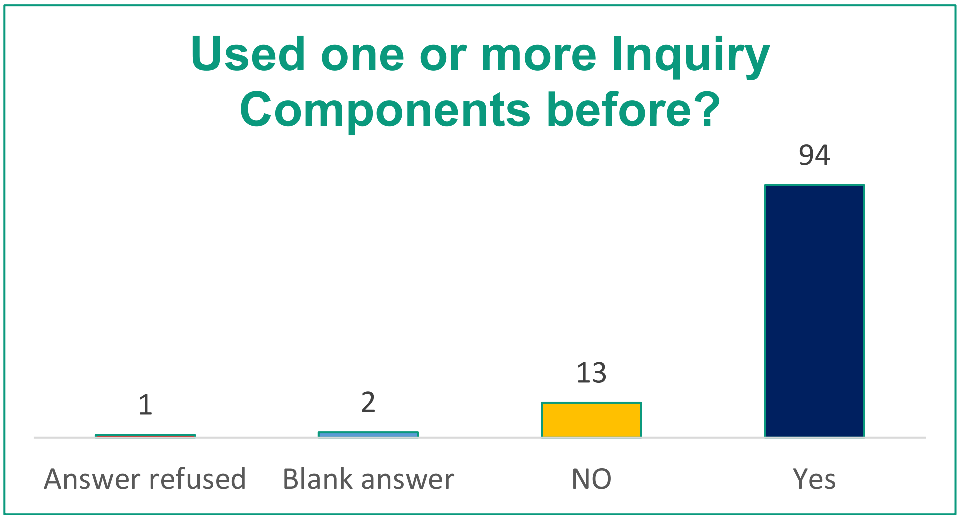
Were you able to introduce interdisciplinarity in your classes, by using the 3D Map?

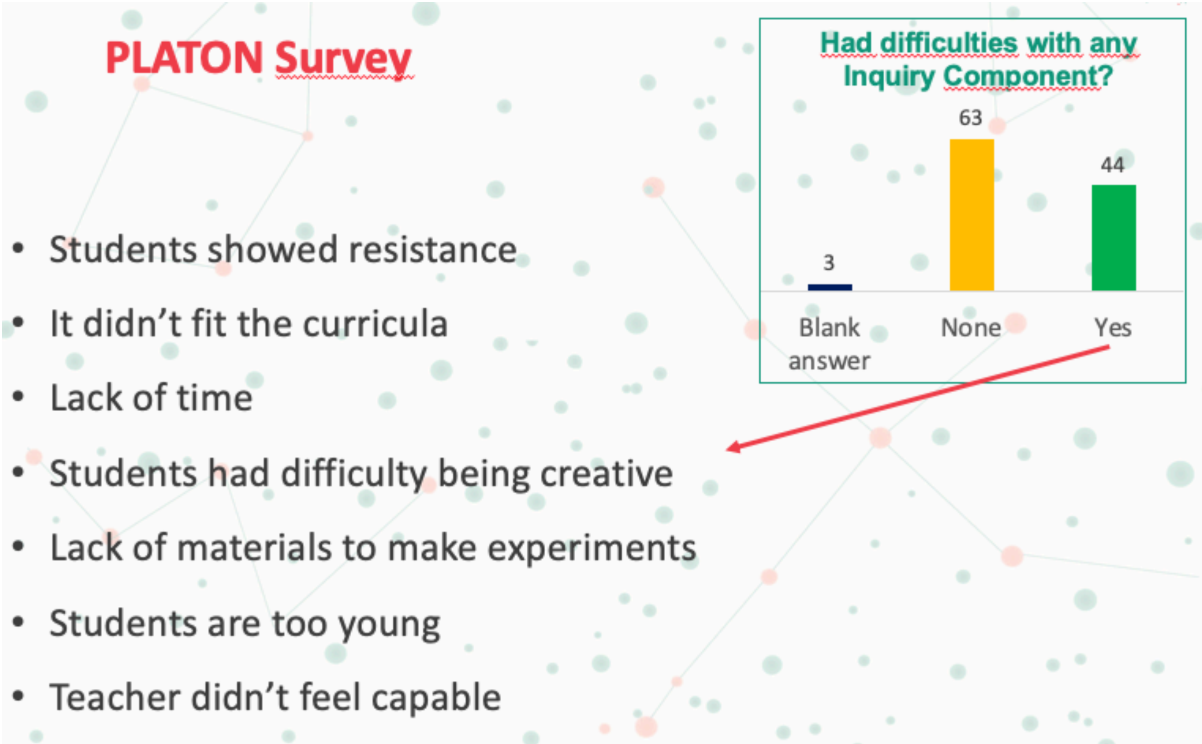


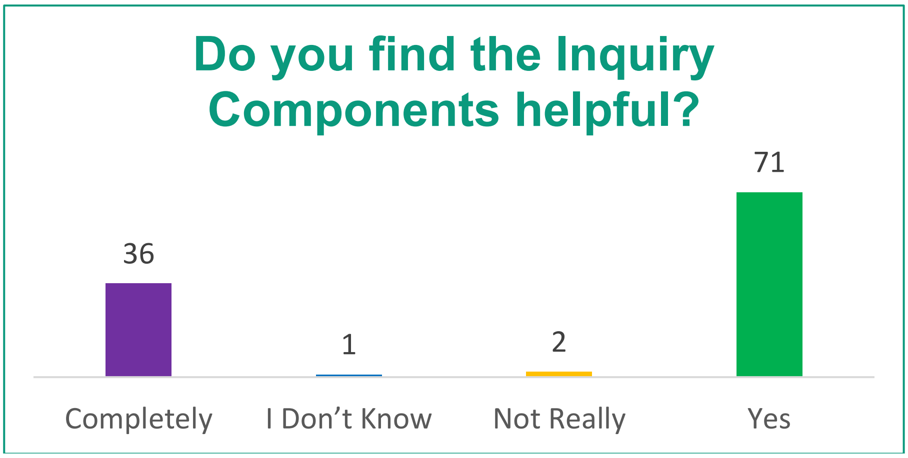



Do you consider the Big Ideas of Science to improve your students understanding of Science as a whole?
18
6
1
5
80
Completely
I Don't Know
Not At All
Not Really
Yes

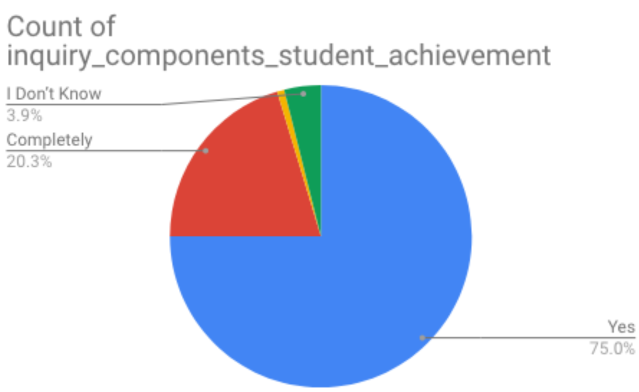

Did you consider the Big Ideas of Science to be useful for your teaching practice?
(76.2% yes, 17.7% completely)
19
3
1
2
85
Completely
I Don't Know
Not At All
Not Really
Yes

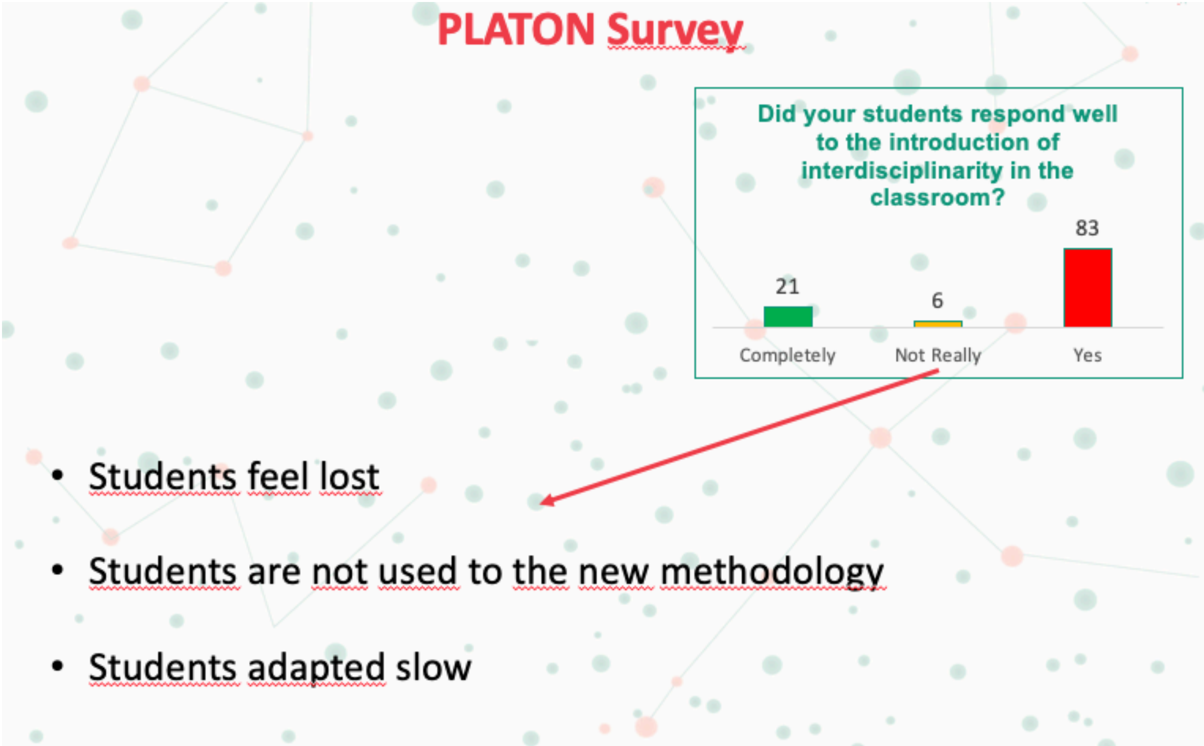

Used one or more Inquiry Components before?
1
2
13
94
Answer refused
Blank answer
NO
Yes



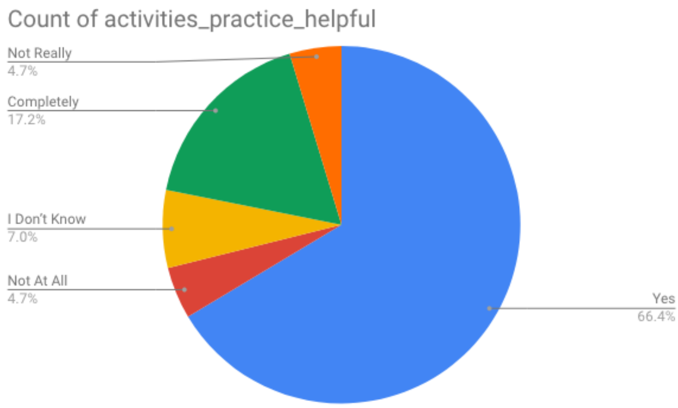


Did the Inquiry Components you implemented until now help your students achieve their learning objectives?

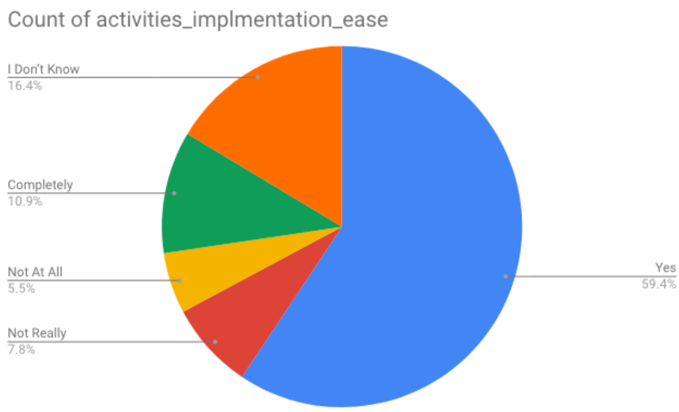




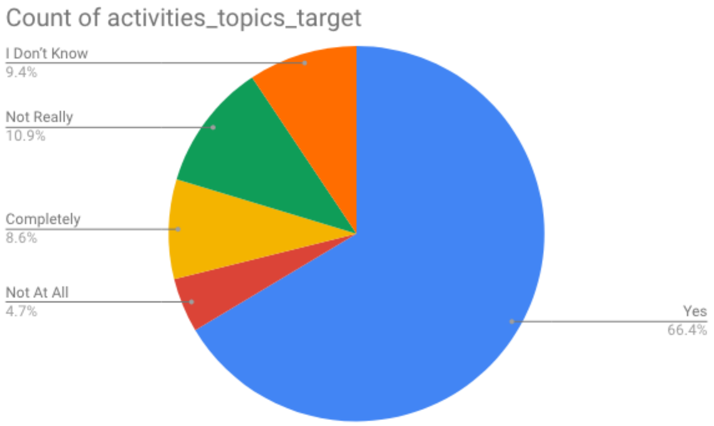
Did you find the PLATON activities helpful for your practice?



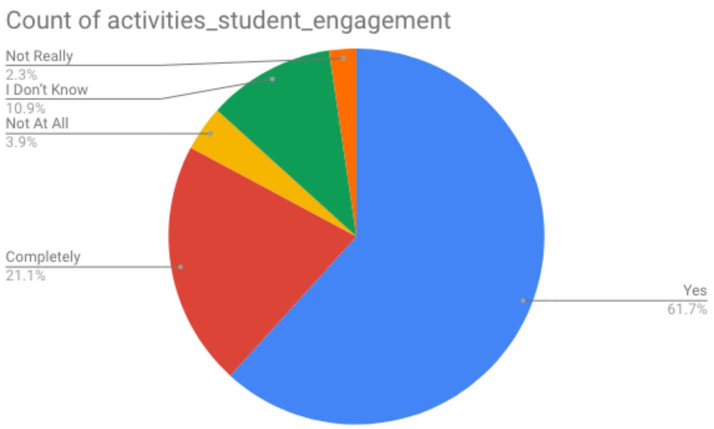
Did you find the PLATON activities easy to implement?



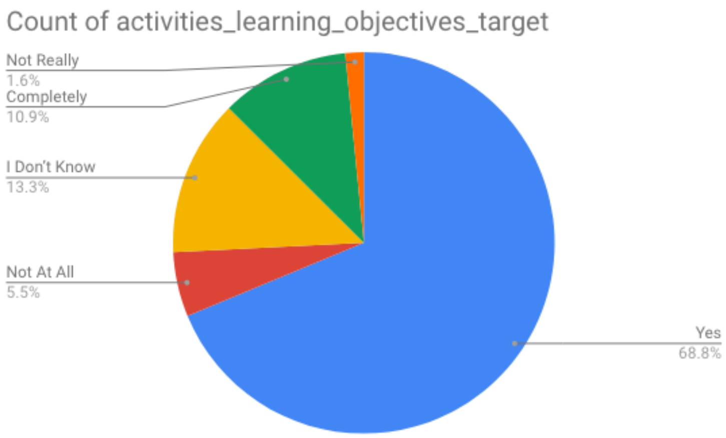
Did the PLATON activities target the necessary curriculum topics?

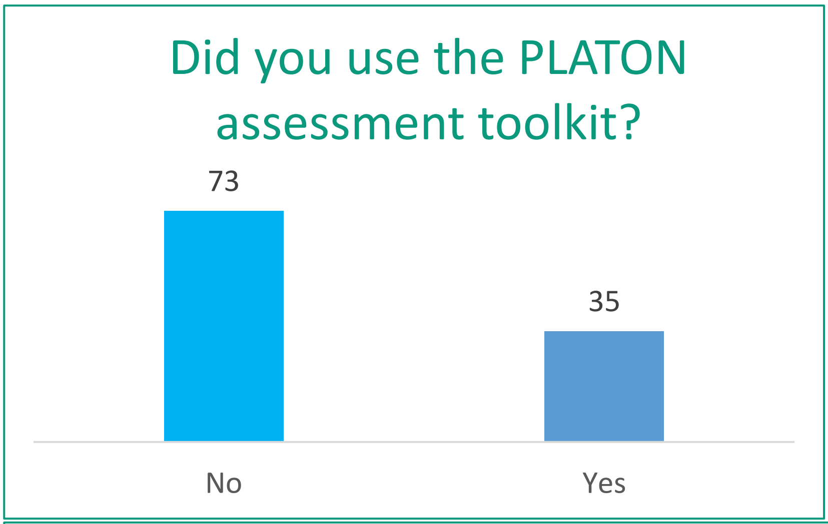


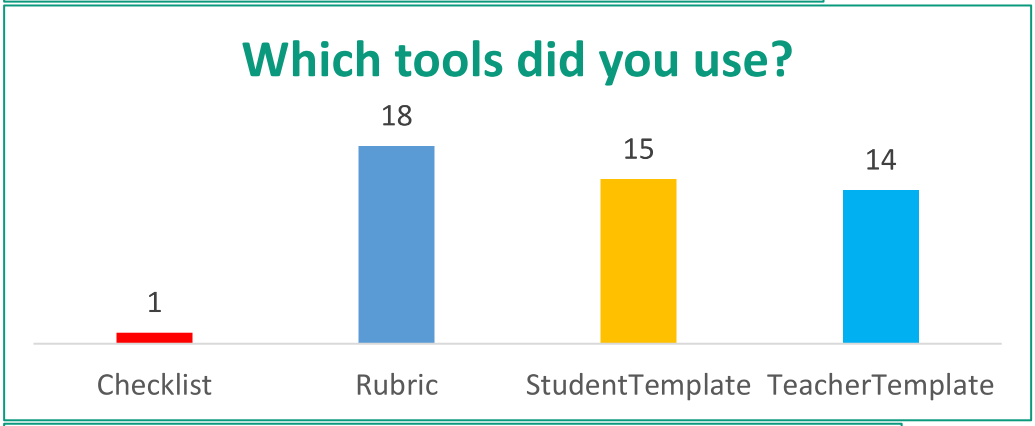
Were your students engaged and motivated when performing the activities?

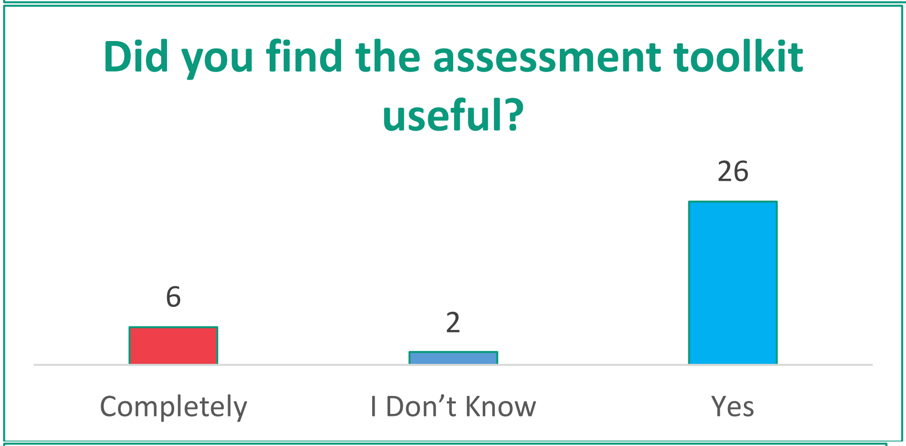


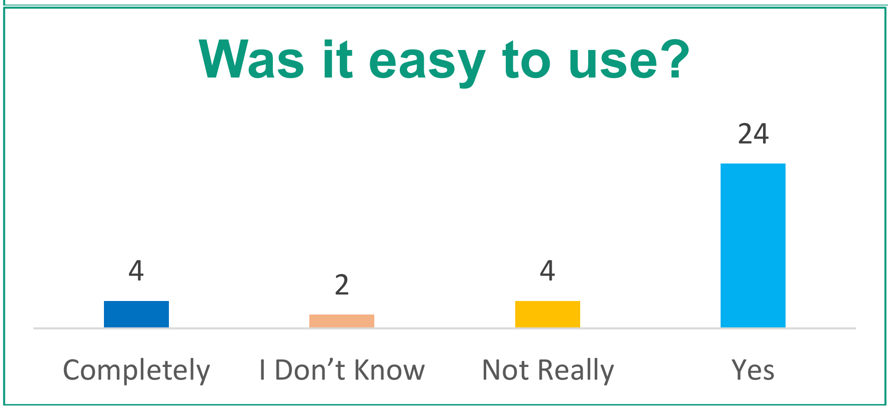
Did the activities target your students' learning objectives?

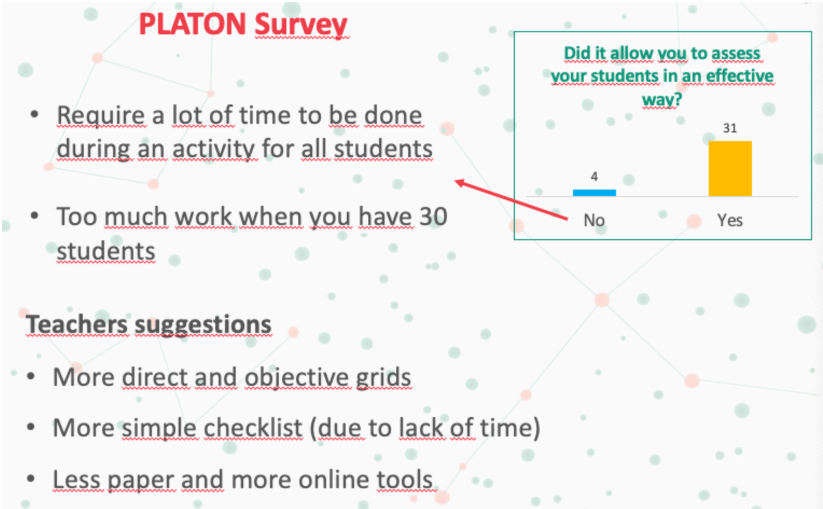


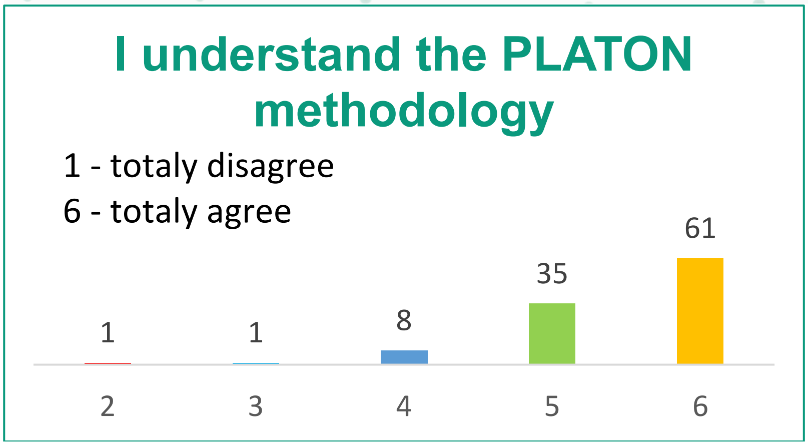

Did you use the PLATON assessment toolkit?
73
35
No
Yes

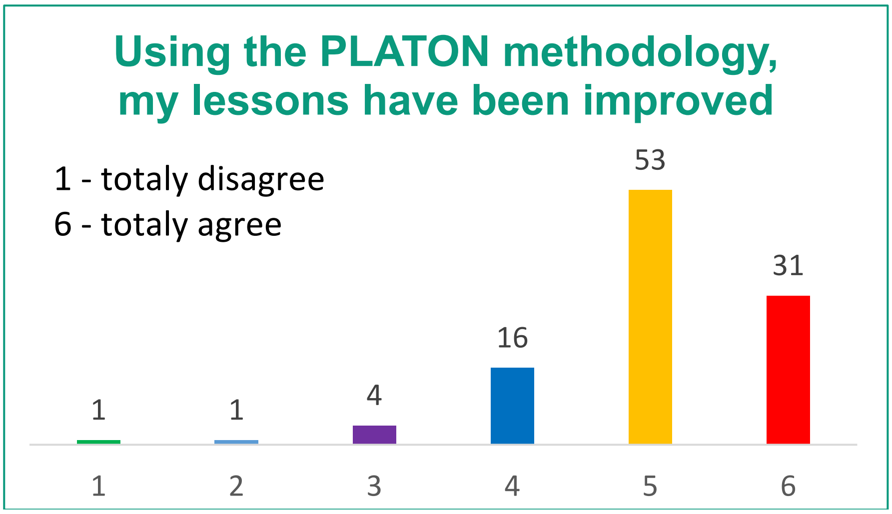

Which tools did you use?
1
18
15
14
Checklist
Rubric
StudentTemplate
TeacherTemplate

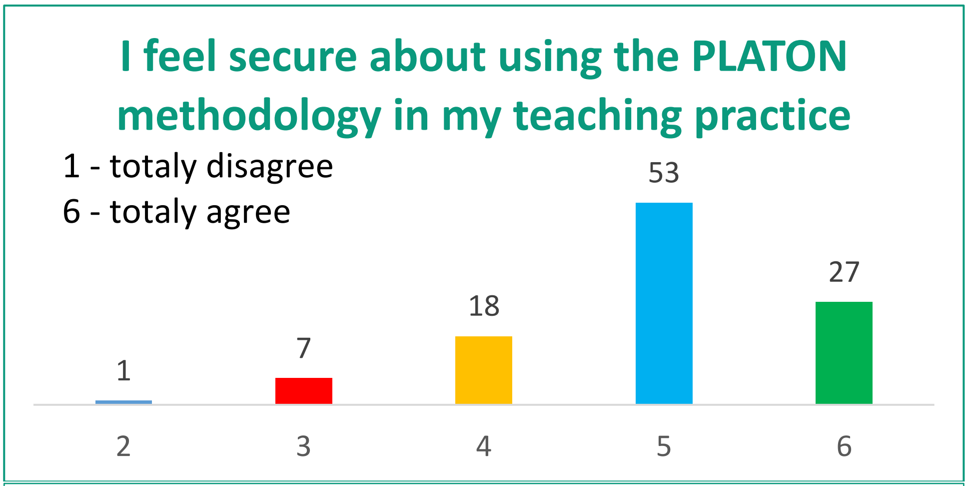

Did you find the assessment toolkit useful?
6
2
26
Completely
I Don't Know
Yes

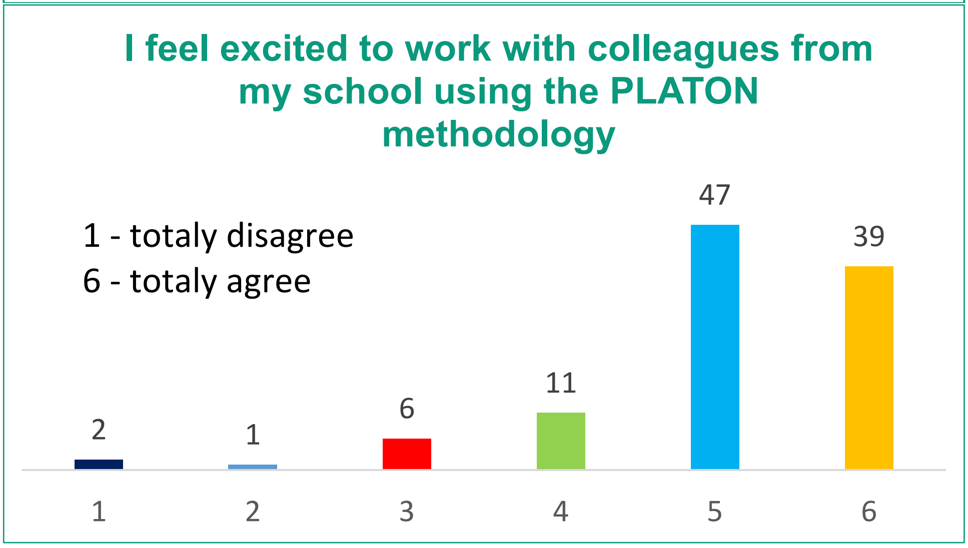

Was it easy to use?
4
2
4
24
Completely
I Don't Know
Not Really
Yes

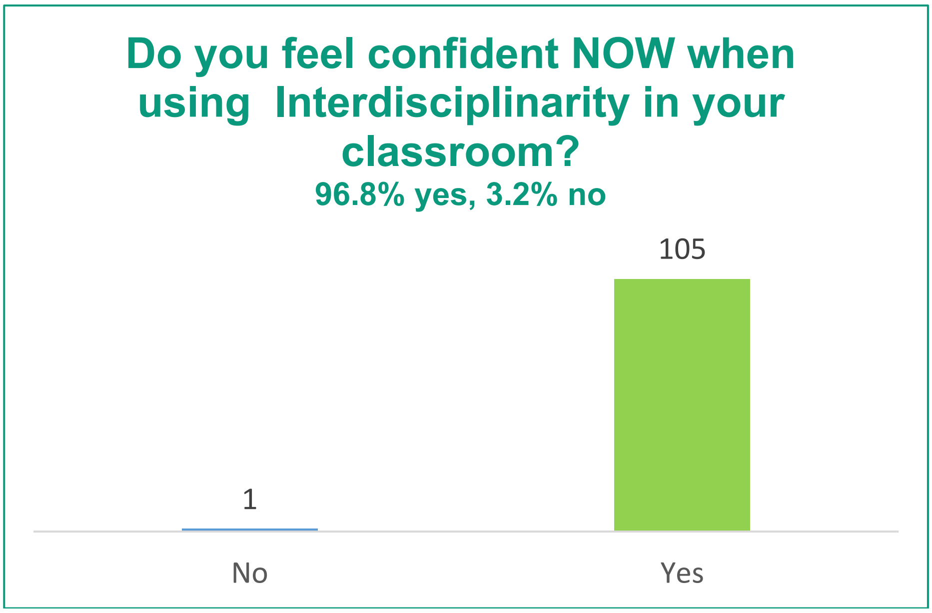

PLATON Survey
Require a lot of time to be done during an activity for all students
Too much work when you have 30 students
Did it allow you to assess your students in an effective way?
4
31
No
Yes
Teachers suggestions
More direct and objective grids
More simple checklist (due to lack of time)
Less paper and more online tools

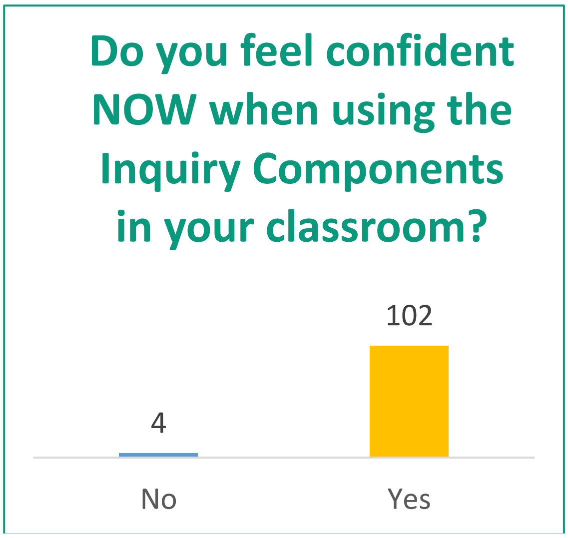

I understand the PLATON methodology
1 - totaly disagree
6 - totaly agree
1
1
8
35
61
2
3
4
5
6

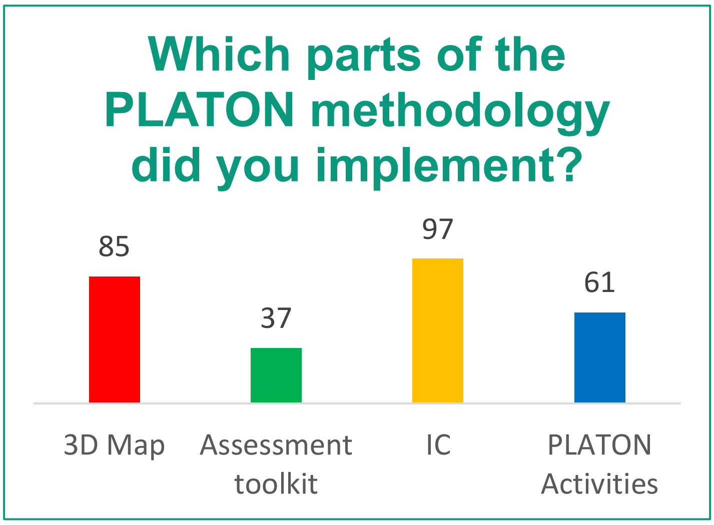

Using the PLATON methodology, my lessons have been improved
1 - totaly disagree
6 - totaly agree
1
1
4
16
53
31
1
2
3
4
5
6

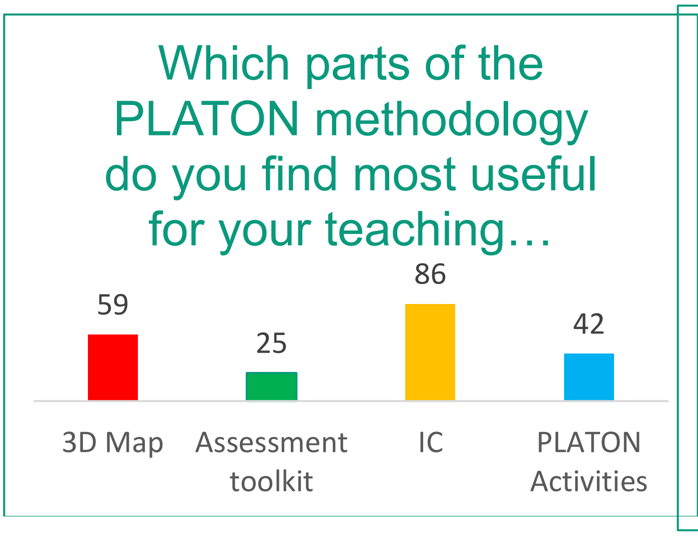

I feel secure about using the PLATON methodology in my teaching practice
1 - totaly disagree
6 - totaly agree
1
7
18
53
27
2
3
4
5
6

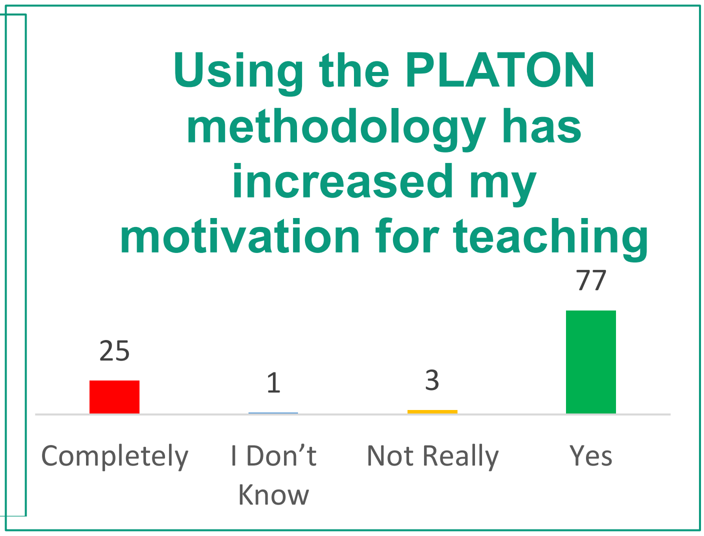

I feel excited to work with colleagues from my school using the PLATON methodology
1 - totaly disagree
6 - totaly agree
2
1
6
11
47
39
1
2
3
4
5
6

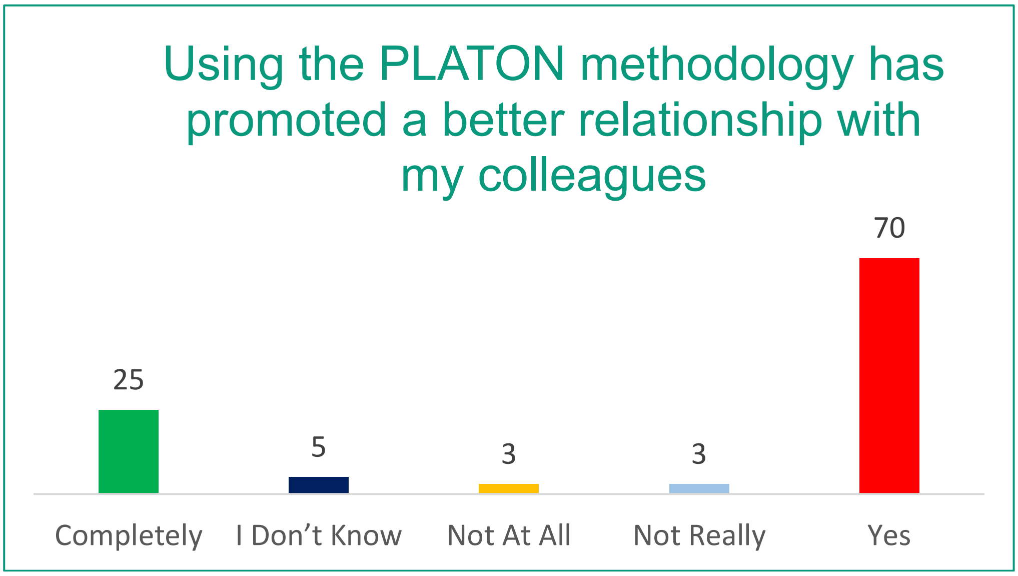

Do you feel confident NOW when using Interdisciplinarity in your classroom?
96.8% yes, 3.2% no
1
105
No
Yes

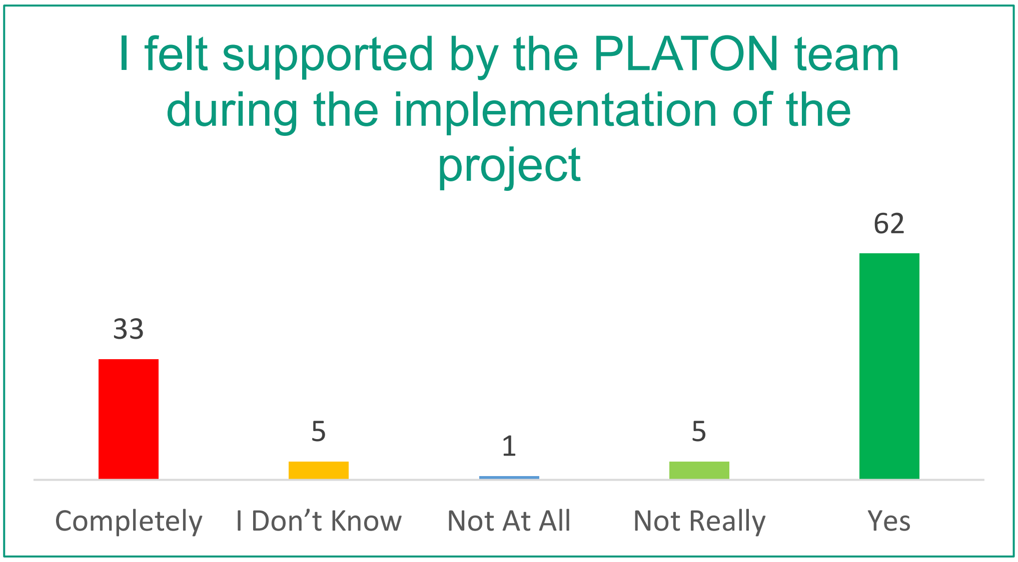

Do you feel confident NOW when using the Inquiry Components in your classroom?
4
102
No
Yes

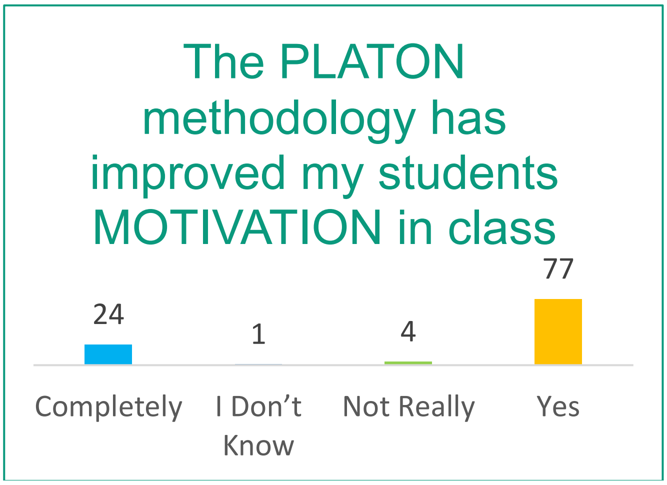

Which parts of the PLATON methodology did you implement?
85
37
97
61
3D Map
Assessment toolkit
IC
PLATON Activities

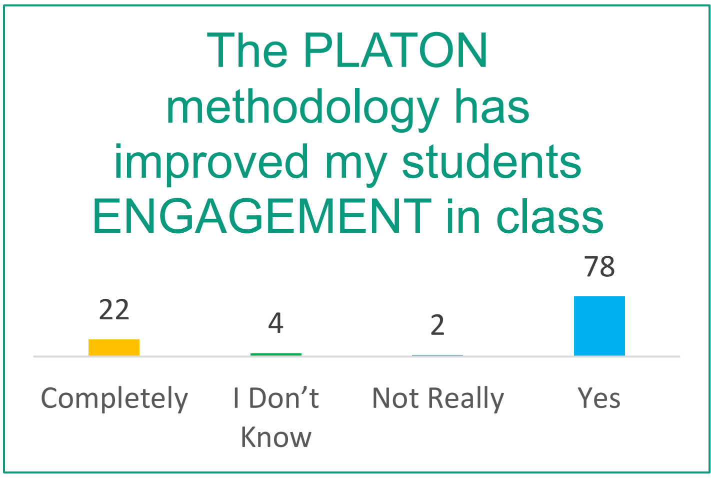

Which parts of the PLATON methodology do you find most useful for your teaching…
59
25
86
42
3D Map
Assessment toolkit
IC
PLATON Activities

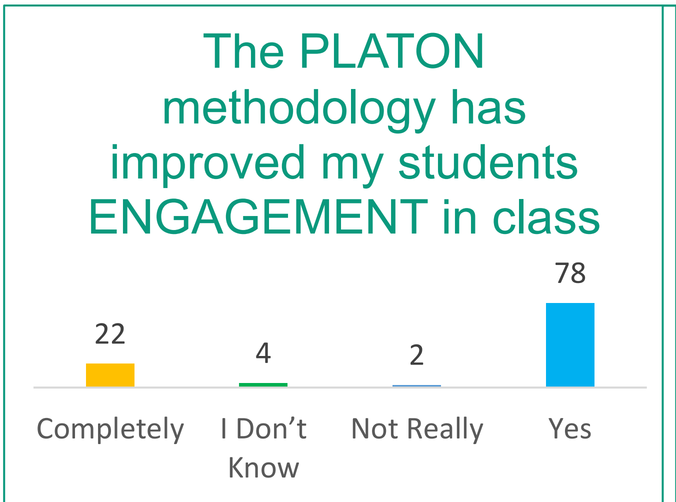

Using the PLATON methodology has increased my motivation for teaching
25
1
3
77
Completely
I Don’t Know
Not Really
Yes

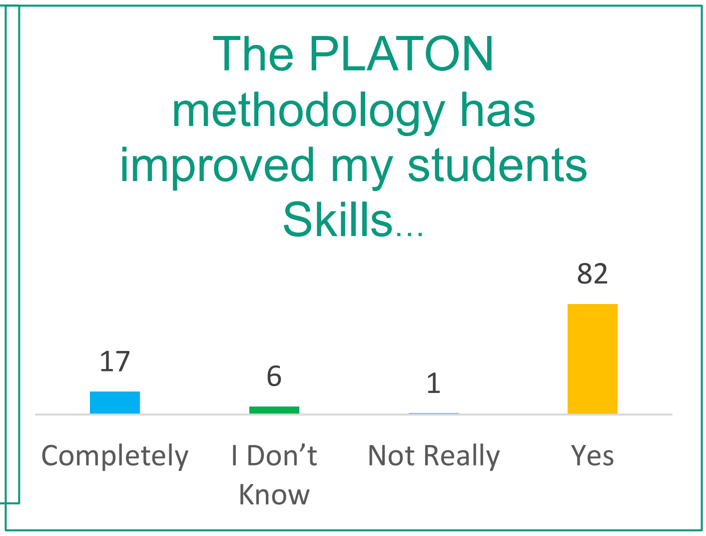

Using the PLATON methodology has promoted a better relationship with my colleagues
25
5
3
3
70
Completely
I Don’t Know
Not At All
Not Really
Yes

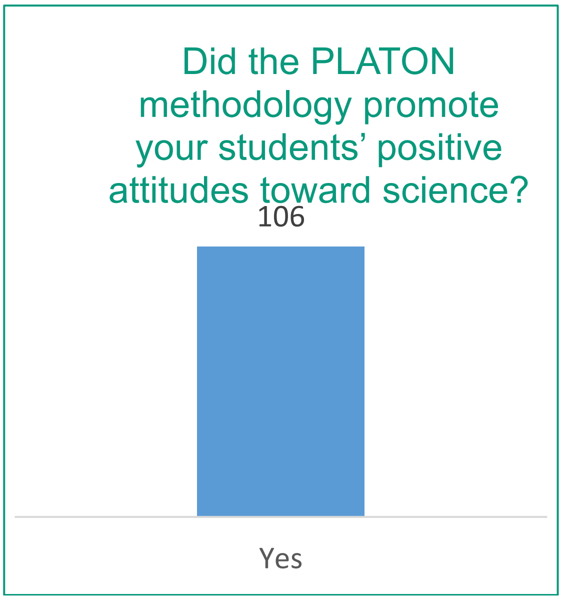

I felt supported by the PLATON team during the implementation of the project
33
5
1
5
62
Completely
I Don't Know
Not At All
Not Really
Yes

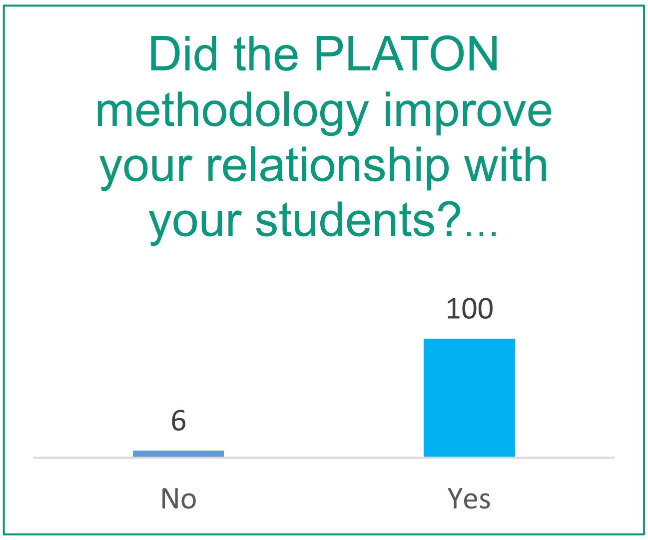

The PLATON methodology has improved my students MOTIVATION in class
24
1
4
77
Completely
I Don't Know
Not Really
Yes


The PLATON methodology has improved my students ENGAGEMENT in class
22
4
2
78
Completely
I Don't Know
Not Really
Yes


The PLATON methodology has improved my students ENGAGEMENT in class
22
4
2
78
Completely
I Don't Know
Not Really
Yes


The PLATON methodology has improved my students Skills...
17
6
1
82
Completely
I Don't Know
Not Really
Yes


Did the PLATON methodology promote your students' positive attitudes toward science?
106
Yes


Did the PLATON methodology improve your relationship with your students?...
6
100
No
Yes

Appendix IX Black Hole in My School Exercise Details

For the Black Holes In My School exercise a series of supporting documents were created and made available in the project online course for teachers and in the inquiry learning scenario for students. In this appendix the key elements for the discovery of a stellar mass black hole candidate are presented. This component had an introduction to Stellar Mass Black Holes and the full procedure for the calculation of the mass of the object. The full implementation of the activity was advised only for Secondary School Students.

Images and parts of the text credited to Fraser Lewis (Faulkes Telescope Educational Team)
BHIMS exercise was developed in the framework of the SoNetTE project

BLACK HOLES IN MY SCHOOL

STELLAR MASS BLACK HOLES

Black holes are regions of space time where gravity shows all its glory and triumph and are thus very important examples of the applicability and importance of General Relativity. They are mysterious objects whose existence is still not completely proven. Definite proof of their existence would come from finding evidence of the existence of an event horizon, a point of no return. Until such proof arrives the correct attitude is to call them black hole candidates, no matter how promising the many observations of them are.

In spite of all this veil of mystery and uncertainty black holes are the simplest objects in the Universe. They can be completely characterized by only 3 parameters: charge, mass and angular momentum. This implies that black holes in the centres of galaxies and those living in stellar systems have only one fundamental difference: their mass. There are strong arguments implying that stellar mass black holes might be born from the supernovae which occur after the death of some high mas stars, stars with masses 8 to 10 times the mass of our Sun or bigger. These massive stars have a very short existence (of the order of millions of years, which is very short when compared to the life of a star like our Sun. Our Sun has existed for nearly 4.5 billion years (10^9 years) and is halfway through its life time. The final stage of the life of a high mass star is in the form of a supernova explosion. The remains of the progenitor star are expected to be in general either a neutron star or a black hole, depending, in part, on the mass of the remaining object.
So far we know nearly 2 dozen very strong candidates for stellar mass black hole candidates in our own Galaxy. Their proximity turns them in real laboratories where we can study their characteristics and thus gain knowledge about their true nature and perhaps infer probable characteristics of those living in the centres of galaxies. An artistic view of a stellar mass black hole system is depicted in Figure 149.

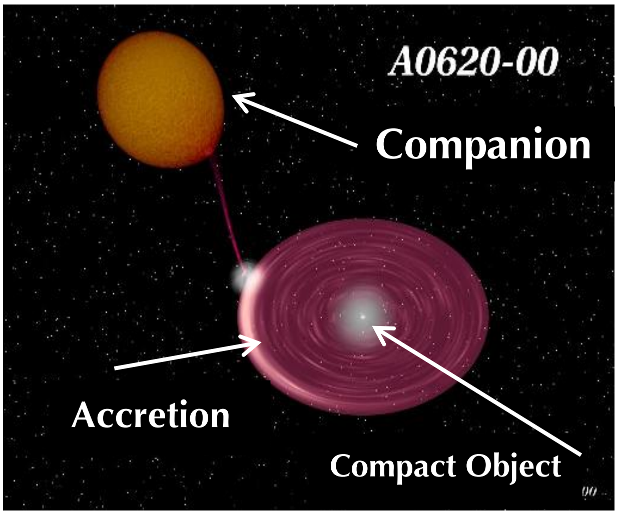


Figure 149 Artist Impression of Stellar Black Hole Candidate A0620-00.
A binary system composed of a low mass star and a compact object. The material of the companion star is attracted by the intense gravitational field of the compact object forming an accretion disc surrounding it. (Credit and Copyright: Robert Hynes)

HOW STELLAR MASS BLACK HOLES FORM?

Let's begin by gaining some understanding of the life cycle of stars.

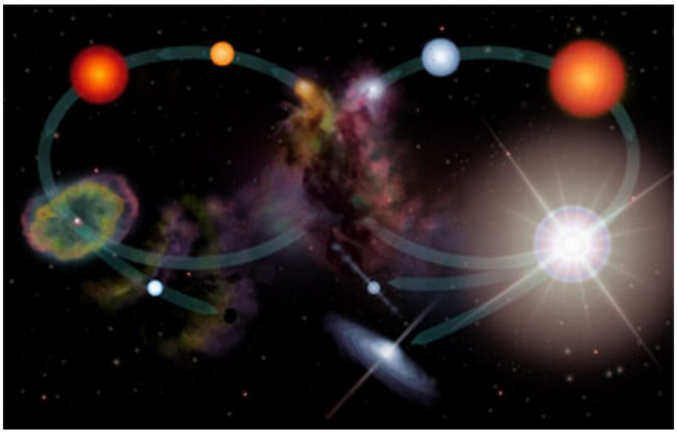


Figure 150 – Two different evolutionary cycles of stars depending on the initial mass (Credit: NASA)

In Figure 150 the life cycle of stars are presented depicting two major evolutionary paths, depending on the initial mass of the star. In the central part of this artist's impression a nebula of gas and dust gives birth to stars with different masses. In the left part of the image is represented the evolutionary cycle of a low mass star (like our Sun), that will end its life as a white dwarf. In the right part of the image is represented the evolutionary path of a high mass star that will end up as a neutron star or a black hole. The luminosity of stars during most of their lives is due to nuclear reaction where hydrogen is being fused into helium. These reactions are only possible due to the extreme temperatures existing in the interior of such objects. The radiative pressure is generated from such phenomena counterbalances the gravity field originated by the star's own mass, enabling the star to stay in a state of equilibrium.

When the fuel diminishes (in this case hydrogen), the radiation pressure diminishes and the star's core contracts due to the action of the gravitational field. There is an increase in temperature in the regions closer to the core, which makes it possible for the hydrogen combustion layer to move gradually towards the surface. The star, in search for a new equilibrium state, will expand. The radius of the star increases and the star transforms into a red giant or red supergiant depending on its initial mass.

While the star expands the core contracts. There is a new increase in temperature and depending on the original mass of the star, the temperature and density may increase enough to originate new reactions and start transforming helium core into a mixture of carbon and oxygen, or , in higher mass stars, oxygen, neon and magnesium. During this period the external layers of the star are dispersed into the interstellar medium (in high mass stars, the lost fraction represents a big part of the total mass), while the core, where fuel (heavier elements) also starts to run out, continues to contract and heat up to higher temperatures. The element transformation continues until the formation of iron. Iron is a stable element and to transform it into heavier elements the star would need an external source of energy. From this moment on the star gets unstable and ends up in a supernova explosion where all the outer layers are released into the interstellar medium. Elements heavier then iron are formed in this phase.

Stars like our Sun (low mass stars) have a much longer life cycle, with a duration of the order of billions of years and end up their lives in the form of a white dwarf. They start by fusing their Hydrogen fuel into Helium and then continue fusing Helium into carbon and oxygen.

Stars with a mass higher than 10 solar masses will follow a much shorter life cycle, of the order of millions of years. Due to their higher mass they need more fuel in order to maintain the equilibrium state, thus consuming more rapidly their source of energy. It is believed that their end state will be in the form of a neutron star or a black hole.

WHITE DWARFS

Figure 151 - NGC 2440 is a Planetary Nebula located 4000 light years away from Earth. The central star evolved to a white dwarf after ejecting its outer layers originating this beautiful planetary nebula (Credit: NASA & Hubble Heritage Team)

Low mass stars end up their life cycle in a much more peaceful way when the core slowly loses contact with the outer layers. High energy photons originating from the stellar core slowly excite the material of these outer layers, already very tenuous and dispersed, producing as a result the incredible beautiful planetary nebula such as the one in Figure 151.

The remaining part of the star has the form of a white dwarf. In these stars matter is so compressed that atomic nuclei are "glued" to each other. A state where there are no atoms, only nuclei and free electrons. The collapse of the star is now stopped by the electrons' degeneracy pressure, a pressure that emerges from the impossibility of 2 electrons occupying the same quantum position at the same time. If we try to put 2 electrons in the same atomic orbit an effect similar to electromagnetic repulsion, when we try to approach particles with the same charge, will appear. In this case the effect is known as the Pauli exclusion principle: "two electrons can't occupy the same quantum state".

In the core of the stellar remains the pressure is so large that the necessary conditions for such a force to appear and the degeneracy of electrons is then responsible for stopping the gravitational collapse, thus stabilizing the star.

White dwarfs are extremely hot and emit thermal radiation. The first white dwarf observed was Sirius B, companion of Sirius, one of the brightest stars in our skies. Sirius B has a radius smaller than that of the Earth but has almost the same mass as our Sun. White dwarfs are so dense that a tea spoon of their material would weight 50 tonnes, by Earth standards!

The discovery that the electrons degeneracy pressure could halt the collapse of a star was made by an Indian physicist, Subrahmanyan Chandrasekhar, when he was 20 year old, while making the boat trip that took him from India to England where he was about to start his PhD. He calculated that only stellar remains that had a mass lower than 1.44 times the mass of the Sun could reach a state of equilibrium due to the electrons' degeneracy pressure. This will be the destiny of our star, the Sun.

When this limit is surpassed the continuation of the collapse is inevitable until the next stage, where it can be halted again in the formation of neutron stars.

NEUTRON STARS

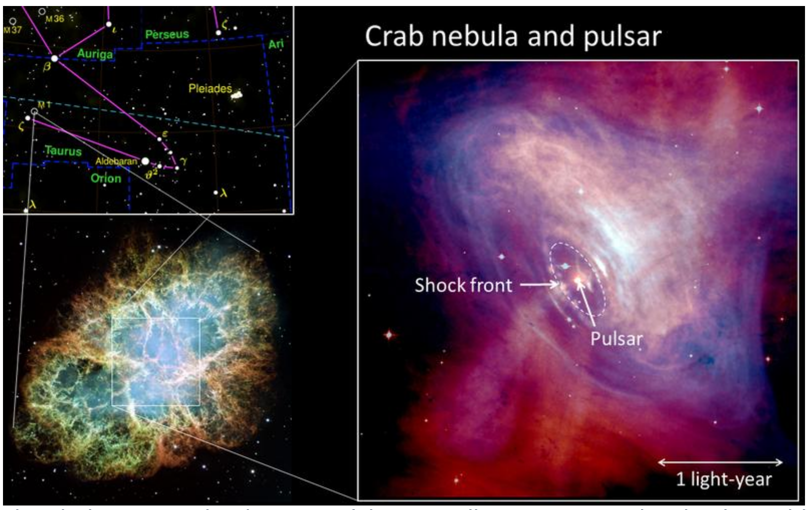


Figure 152 - The Crab nebula (M1) in the direction of the constellation Taurus, taken by the Hubble (lower left). The details to the right are showing a composite of visible light (red) and X-rays (blue) with the pulsar as central star. At the shock front in 0.3 light-years distance from the pulsar, the ultra relativistic wind of electrons and positrons collides with the surrounding nebula. (Credits: NASA

If the progenitor star has an initial mass higher than 8 solar masses, the transformation process of hydrogen into helium and so on towards heavier elements will continue until the stage where the core of the star is composed essentially of iron. In order to transform iron in heavier elements it is necessary to find an external source of energy. In the absence of the radiative pressure from the core of the star the collapse is inevitable and very quick. The star loses contact with the outer layers. With a mass higher than 1.44 solar masses, the electron degeneracy pressure is not enough to halt the gravitational force and the star's core collapses. The electrons can't resist the gravitational pull and start interacting with protons from the core producing neutrons. In this case, and provided the mass is not higher than 3 solar masses, a new equilibrium state can be reached, this time due to the degenerative pressure of the neutrons, the quantum effect that prevent neutrons to occupy the same state. The pressure created by this "package" of neutrons will counterbalance the gravitational force and the star will reach a new equilibrium state in the form of a neutron star.

In Figure 152 we can see an image of the Crab Nebula, a supernova remnant, at a distance of 6 000 light years from Earth, first observed by the British amateur astronomer John Bevis. On the right hand side of the image we can see the interior of the nebula where a pulsar was observed (a neutron star that emits regular radio pulses). The pulsar is visible in the central part of the image. The rotational period of a pulsar is extremely small. In the case of the Crab Nebula's pulsar it is 33 times per second.

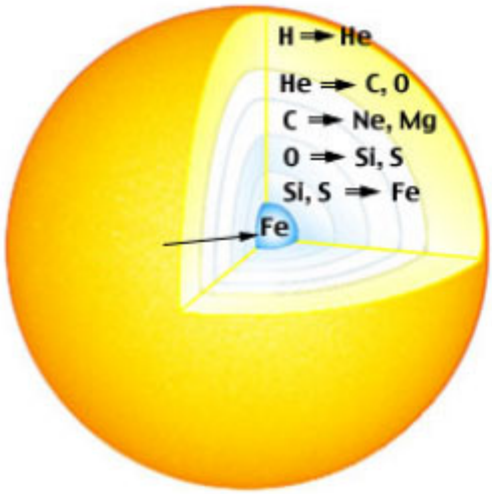


Figure 153 A high mass star's life cycle ends when the core is essentially constituted by Iron, a stable element that can't be transformed into heavier elements unless an external source of energy is provided to the star (Credit: NASA)

As mentioned before, if the progenitor star has an initial mass around 8 solar masses, the transformation process continues until a state where the star's core is constituted essentially by iron. At this stage the star resembles an onion where each layer is constituted by different elements, produced during the evolutionary cycle of the star in Figure 153. The outer layers that can't follow the collapse of the core undergo a slower contracting process ending up with a collision with the degenerate core. This process ends up in the form of a supernova explosion type II, one of the most energetic phenomena in the Universe. In this phase the star releases into the interstellar medium all the elements that it has produced in its interior. The interaction of the radiation coming from the core with the star's layers, during the explosion, will generate the necessary energy for the emergence of elements heavier than iron. This is the mechanism with which the Universe is enriched with the heavier elements for the periodic table that didn't exist in the primordial Universe, that was constituted basically by hydrogen and helium and a small quantity of lithium. As Carl Sagan used to say, we are all children of the stars, all made of stardust.

The remains of such an explosion, depending on the mass, can be a neutron star or a black hole. Neutron stars have usually a radius of around 10 km, usually with a mass of the order of 1.5 solar masses. The first detection of a neutron star was made by a Northern Irish astronomer, Jocelyn Bell, a PhD student at the time of the discovery, in 1967. She discovered a radio signal that pulsed with such an amazing periodicity that at the beginning she thought could be a message from aliens. Soon it was confirmed to be a signal coming from a neutron star. These objects have intense magnetic fields (in fact they have the most intense magnetic field that we can measure in the Universe, billions of times stronger than the Earth's magnetic field). These magnetic fields create the vibration of the electrons, responsible for the emission of radio waves. Neutron stars with such characteristics are known as pulsars. These are objects with fast rotation and their pulses can have a periods of milliseconds. The final effect is similar to the light emitted by lighthouses. It is important to note however that not all neutron stars are pulsars.

BLACK HOLES

If the remains of the progenitor star has a mass higher than 3 solar masses, which may happen in cases where the original star may have masses higher than 40 solar masses (the relation between the initial mass and the mass of the remaining object is not yet well established), then not even the degeneracy pressure of neutrons can stop the gravitational collapse and the star will contract due to its own gravitational field giving birth to a black hole.

A black hole is by definition a region of the Universe which nothing can come out of, not even light. This property was responsible for the baptism of such objects as "black holes" by the theoretical physicist John Wheeler in 1967. In fact, the existence of objects where the escape velocity was higher than the speed of light (the minimum necessary speed for an object to escape the gravitational attraction of the body), was already predicted in 1783 by an English priest, John Michell, and in 1796 by Pierre Simon Laplace, both predictions based in the Newtonian Mechanics. The big change since then is that at the time these predictions were made it was not known that the speed of light was a limiting value.

The escape velocity on Earth is 40.248 km/h (40 thousand and two hundred and forty eight km/h), already reached by aerospace technology. However, if the density of our planet increased a lot, if we contracted the whole Earth to a radius of 10 mm then the scape velocity would increase and surpass 300 000 km/s, a speed higher than the velocity of light, thus impossible to reach.

In the framework of General Relativity the existence of black holes emerges as a marginal result to one of the most important solutions to Einstein equations, the solution discovered in 1915 by Karl Schwarzschild. This solution describes the vacuum region external to a static and spherical body. It is perfect to study the dynamics in the Solar System and provided important proofs of predictions made by Einstein's theory. This solution predicts that a body may contract to a value less than a certain radius, the Schwarzschild radius (also known as event horizon), turning into a black hole. In km this value is equivalent to 3 times the mass of the star in solar mass units.

G = Newton's gravitational constant = $6.67 \times 10^{-11} m^3 s^{-2} kg^{-1}$

C= light speed = 3.00×10^{8} m/s
1 MΘ (1 Solar Mass) ≈ 1.99×10^{30} kg

Schwarzchild Radius = 2 GM/c² = $\frac{13{,}34 \times 10^{-11}\, \text{M}}{9 \times 10^{16}} \frac{\text{m}^3 s^{-2}}{\text{kgm}^2 s^{-2}} = 1{,}482 \times 10^{-27} \text{M}\, \frac{\text{m}}{\text{kg}}$ = $1{,}482 \times 10^{-27} \times 2 \times 10^{30} \text{M}\, \frac{\text{m}}{\text{M}\odot}$

Schwarzschild Radius = 2 GM/c² ≈ $3\, \frac{\text{M}}{\text{M}\odot}\, km$

Approximately 3 times the mass of the star in solar mass units and the result given in km. A typical black hole candidate has a mass of approximately 10 solar masses and an event horizon of approximately 30 km. Most neutron stars and black hole candidates discovered so far are part of a binary system composed by a star of a known spectral type and a compact object. The intense gravitational field of these objects will attract the material of the companion star forming an accretion disk around the compact object. The inner part of the disc is subject to a gravitational field more intense and emit higher energy radiation, in the X-ray part of the spectrum. This is the most effective method of discovering such objects, but is not the only one.

HOW DO WE DETECT STELLAR MASS BLACK HOLES ?

(these part of the text is only to get you familiarized with all characteristics related to this field of research)

Figure 154 – UHURU satellite (freedom in Swahili).
Was the first satellite completely devoted to the study of cosmic X-ray sources. It discovered over 400 sources, among them several X-ray emitting binary systems.

From the 60's on astronomers started to have available the necessary technology to observe the sky in the X-ray waveband. Until then there was no knowledge of the existence of an X-ray emitting source in the Universe beyond our Sun. X-rays can't pass through our atmosphere, therefore only spacecraft above it can study the Universe at these wavelengths. The first such device was launched in 1962 by a team of North American scientists. The Italian Ricardo Giacconi, who won the physics Nobel Prize in 2002 for his contribution for X-ray astronomy, was among them. The first discovered source was Sco X-1, receiving this name for being the first X-ray source in the constellation of Scorpius. At that time this source was a mystery to the astronomers: it emitted thousands of times more energy in X-ray than in visible light, and in this waveband the source was billions of times brighter than the Sun! These mysterious sources of radiation started to be unveiled with the launch of the UHURU satellite (Figure 154). This event marked the beginning of a new era of important discoveries unveiling a completely different Universe that could not be seen in the optical. Nowadays there are several active satellites observing the sky in X-ray: Chandra (NASA), XMM-Newton (ESA), RXTE (NASA), ALEXIS (LANL).

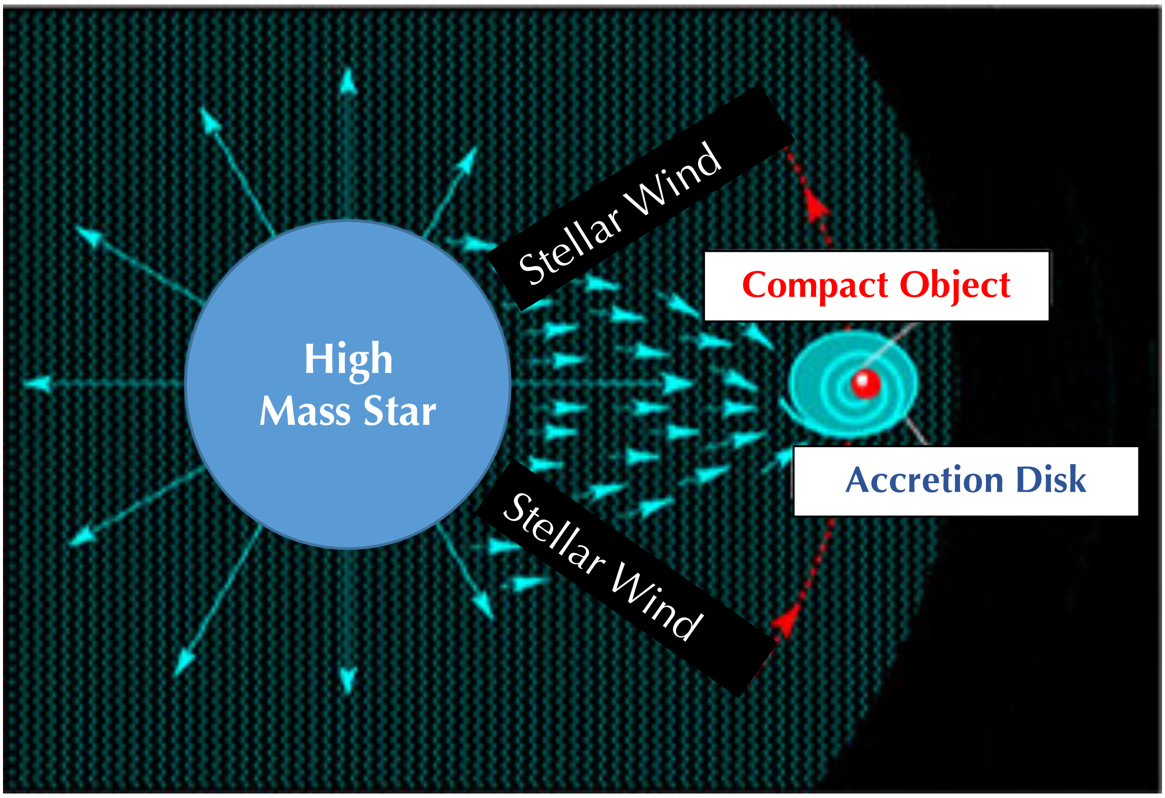


Figure 155 Scheme of the mechanism of accretion by stellar winds. Credit: NUCLIO (C.Zurita)

Hundreds of X-ray sources were detected so far, concentrated in the plane of our Galaxy. Many of these sources are binary systems composed by a star of a known spectral type and a compact object. The gravitational field of this object attracts the material of the companion star. In the regions closer to the compact object high energetic phenomena take place and we can observe the emission of X-rays (Figure 155). In the cases where the non-visible component is a neutron star or a black hole they are called X-ray binaries. If the compact object is a white dwarf, in spite the fact that they are also sources of X-ray, they are called cataclysmic variables. This last case is easy to spot since their X-ray emission is not as intense as in the case of the more compact objects.

In an interesting paradox, these extremely compact objects are almost impossible to detect when isolated. They are discovered since they are responsible for extremely energetic phenomenon that for a short period of time transform them into strong X-ray emitters. Neutron stars and black holes are responsible for some of the most energetic phenomena in the Universe, they can be discovered via their interaction with the surrounding medium or objects such as those in binary systems.
.

The first system detected, in which the compact object is a strong stellar mass black hole candidate, was Cygnus X-1, in 1972 by the UHURU satellite. It is estimated that the compact object has a mass of the order of 5 times the mass of the Sun concentrated in a few kilometres. Its luminosity is due to accretion of matter coming from the companion star, a blue supergiant. Supergiant stars are continuously losing mass due to stellar winds. Part of this gas can be attracted by the compact object releasing X-rays (Figure 155). The gas may then form a small accretion disk. In the inner regions of this disc energy might reach high levels, so high that we can observe X-rays.

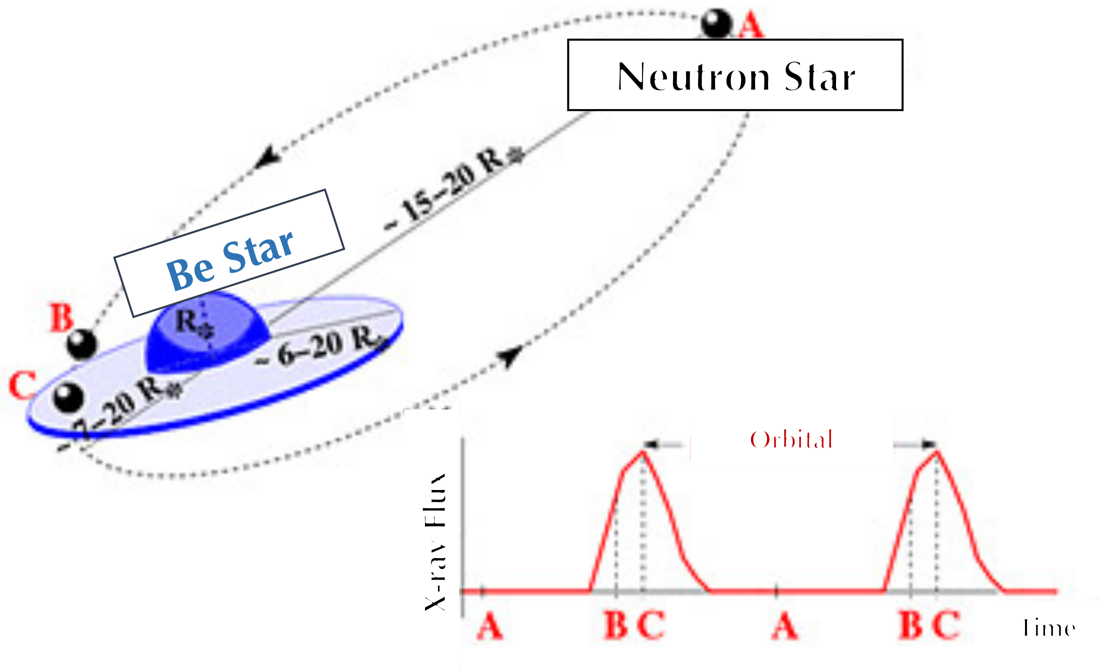


Figure 156 – Scheme of a binary system formed by a Be star and a neutron star.
The X-ray emission occurs when the neutron star, in a particular point of its orbit, enters the circumstellar disk and attracts part of the gas. The X-ray flux increases abruptly at each passage of the neutron star throughout the disc. Credit: NUCLIO (C.Zurita)

The high mass companion star can also be of the Be type. B-type stars are high mass stars much hotter and much bigger than our Sun. The Be type stars are a subtype of this category and are characterized by having a circumstellar disc formed, probably, by the mass of the star lost from the equatorial zones due to its fast rotation (Figure 156). The binary systems formed by a Be star and a neutron star will also produce X-rays if the neutron star, at a certain point of its orbit around the star, penetrates the disc and accrete part of the gas and are therefore known as Be/X-ray binaries.

There are other 2 types of systems in which the companion star has a lower mass than the Sun and are therefore are called low mass X-ray binaries. In these systems the accretion is produced by the material overflowing the Roche lobe, the volume around the star within which the material is gravitationally attached to it. In a binary system, there is a common point between the Roche lobe of the two components, the so called Lagrange point. This is the equilibrium point between the gravitational forces of the two components of the system, in other words, a point where any object would be equally attracted by the star and the compact object.

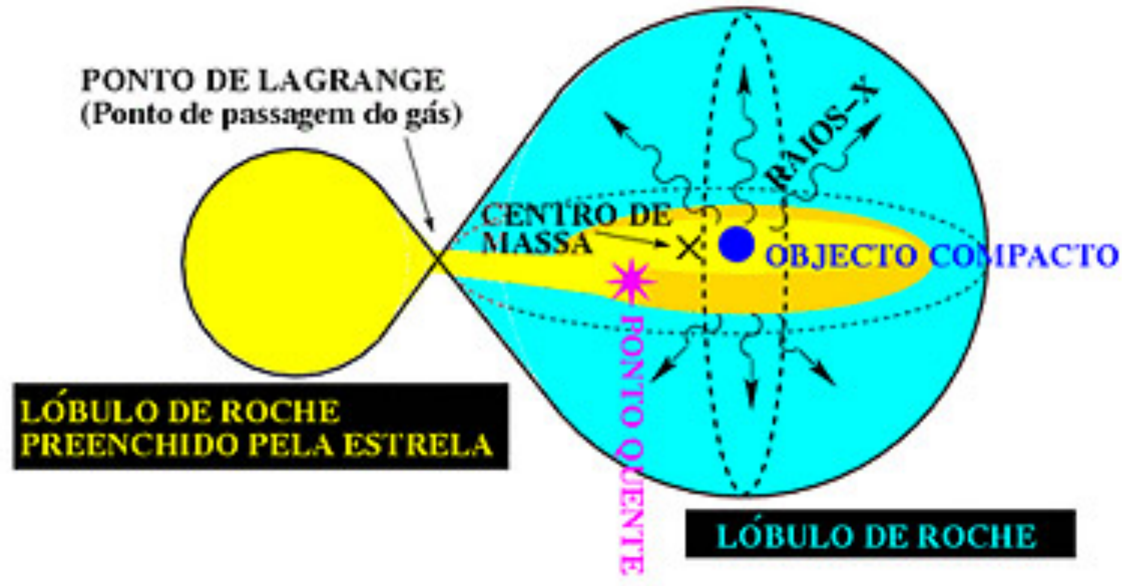


Figure 157 – Scheme of a low mass X-ray binary with Roche lobes represented.
The star fills its Roche lobe and acquires the shape of a pear. All material inside the yellow lobe is attached to the star in the blue lobe to the compact object. The gas in the Lagrange point will flow through this point in the direction of the higher gravitational field. The flux carries with it the angular momentum of the star (rotating at the same speed as the star), thus it won't fall directly to the compact object forming around the star an accretion disc. The point of impact of the gas flow with the disc is called "hot spot" since it is hotter and brighter than the disc itself. In the internal regions of the disc the potential energy of the gas is so high that will emit X-rays.

The Lagrange point is of particular importance since it is the simplest route for the gas to flow from one star to the other. In certain phases of the evolution of the star it can fill its Roche Lobe. This happens in low mass X-ray binaries where the star will deform until acquiring the form of a pear. The gas existing in the external regions, near the Lagrange point will then be attracted by the compact object. Since the system is rotating, the material being transferred will fall in spiral shape in the direction of the compact component forming an accretion disc around it. The accretion process produces X-ray and via reprocessing in the disc, visible radiation. Eventually the accretion mechanism via overflow of the Roche Lobe can also appear in high mass systems alongside with accretion from solar winds (Figure 157).

The fact that we observe X-rays is not evidence of the existence of black holes. It is evidence of the existence of a compact object, which can be a white dwarf, a neutron star or a black hole. The case of white dwarfs is easily solved since, among the binaries with a compact object; these are the weakest X-ray emitters. However, if the compact object is a neutron star or a black hole, then the distinction is more complicated since the gravitational potentials of a black hole and a neutron star are very similar and their observational properties very similar. If the binary system contains a neutron star, as seen before, it may emit regular pulses. Since the magnetic field of the neutron star is very intense the gas may be accreted by the magnetic poles producing the same effect as a light house emitting radio pulses. These systems are so called X-ray pulsars. Sometimes the magnetic field is not so strong, as in the case of the low mass X-ray binaries, and the pulses are not so regular but more erratic and unstable. In these cases we say that they display quasi-periodic oscillations (QPOs). In addition they can also produce thermonuclear flashes on the surface of the neutron star. The flashes are produced when the gas (mainly hydrogen) accreted accumulates on the surface until the conditions are appropriate to start nuclear reactions that first consumes the hydrogen and then the resulting helium. Since helium's fusion is in explosive flashes and can be observed with more or less regularity. In summary, if we observe pulses or flashes in a X-ray binary, we can be sure it contains a neutron star (Figure 158).

But not all neutron stars emit pulses or flashes. In such cases, one way to distinguish between a neutron star and a black hole is by determining the mass of the non-visible component. If the mass of the object is above 3 solar masses than we have a strong black hole candidate.

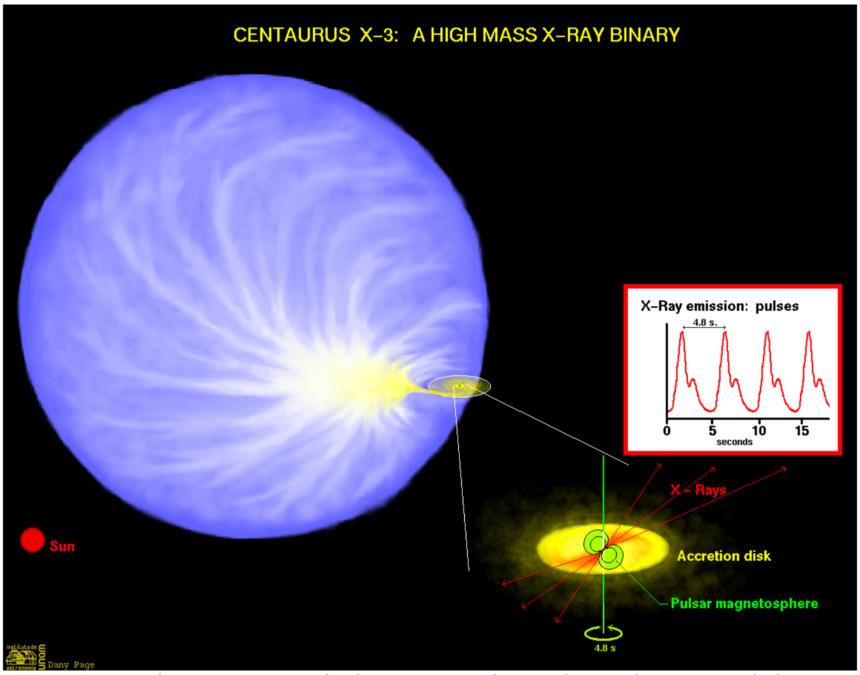
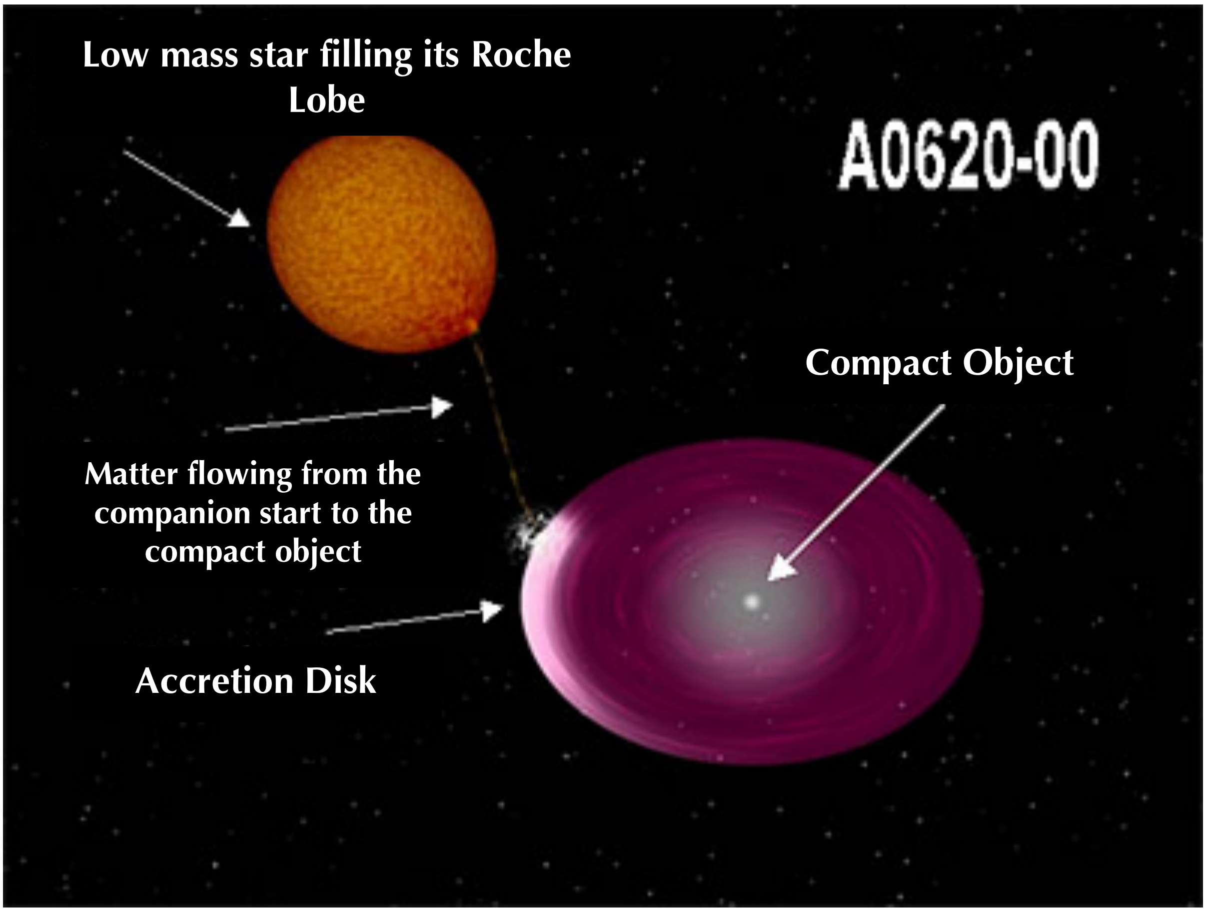


Figure 158 Artistic impression of Centaurs X-3 a high mass X-ray binary located at 30 000 light years from Earth. The compact object is a neutron star with a mass around 0.8 solar masses in orbit around a blue super giant. This was the first system where periodic X-ray pulses were detected. (Credit: Dany Page)

HOW CAN WE DETERMINE THE MASS OF A STELLAR MASS BLACK HOLE ?

Most stars live in binary systems. If one of the components of the systems has enough mass, it will end its days in the form of a supernova. The remain will be transformed into a compact object, a neutron star or a black hole. If the binary system survives the supernova explosion, it can then create a low mas X-ray binary (or LMXB). We only know about 150 such objects in our Galaxy, a low number when compared to the 100 billion stars in our Galaxy. From these 150 less than 2 dozen have an estimate for the minimum mass of the compact object. It is precisely from the orbit of stars around non visible objects that we can determine the mass of



the compact component in a X-ray binary.

Figure 159 – Artist impression of the low mass X-ray binary A0620-00.
Discovered in 1975 it rapidly became a promising stellar mass black hole candidate, a prototype to the study of other candidates. However, the definitive determination of its mass was not yet possible and the limits to its value are too close to the limiting value for a neutron star, around 3 solar masses. (Credit: Robert Hynes)

Low mass X-ray binaries are almost always detected by being strong X-ray emitters. In some of these systems the strong emission phase is a transient phase, i.e., has a very short duration. In these systems the flow of matter in the direction of the compact object has a spasmodic behaviour. Most of the time, matter coming from the star will accumulate in the outer parts of the disc until an instability is generated and the gas is suddenly accreted. An intense eruption is produced and the brightness of the system may have a variation of 5 to 6 magnitudes (Figure 159). After a period that might last a few months the system returns to its normal rhythm, a phase coined as quiescent phase. In this phase all the important studies to determine this system's parameters take place.

Contrary to what happens in persistent X-ray binaries, in which the emission coming from the disc continues, in the transient X-ray binaries the intense emission stops and allows other characteristics of the system to be observed. Once the accretion disc stops being so bright, the companion star becomes visible again. The X-ray transients go completely unnoticed in the middle of hundreds of millions of stars until the moment of the eruptions. The interval between eruptions in these cases is very long taking sometimes decades to take place again. For this reason the discovery of such objects is not so frequent.

THE MASS FUNCTION

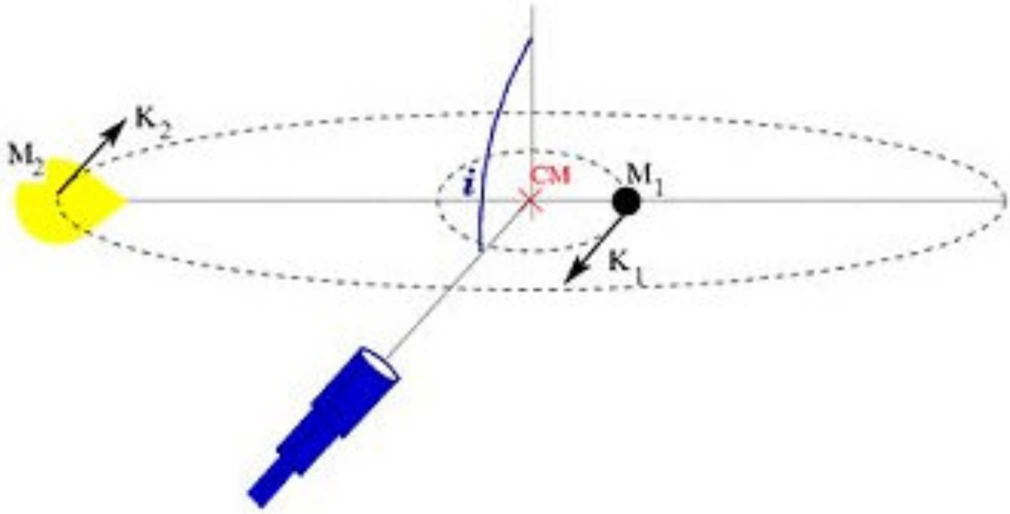


Figure 160 Scheme of a binary system.
The compact object (mass M_1) and the companion star (mass M_2) are orbiting the centre of mass (CM) of the system with radical velocity K_1 and K_2 respectively. Since the compact object is not visible we have to extract all the necessary information by observing the companion star and its orbit. Credit: NUCLIO (C.Zurita)

When a transient system is discovered, it is necessary to wait several months for the star to be responsible for the major emission coming from the binary system and not the disc. By then the observations of the companion star are crucial in order to determine the orbital parameter of the system and be able to apply Kepler's third law (Figure 160). This law states that the square of the orbital period is proportional to the cube of the average distance between the components of the system. We have to remember that Kepler's third law emerges naturally from the application of the Newton's Universal Law of Gravitation to the movement of planets and can therefore be generalized to any two bodies orbiting each other. With the application of Kepler's law to the star we are closer to our objective, determining the mass of the invisible compact object around which the other star is orbiting, i.e., determine the mass of the possible black hole. After some mathematical manipulation in the formula of Kepler's third law we end up in a relation between the orbital parameters of the binary system:

$$\frac{M_1^3 \sin^3 i}{(M_2 + M_1)^2} = \frac{PK_2^3}{2\pi G}$$

where M_1 and M_2 are the masses of the compact object and the companion star respectively, P the orbital period, i.e., the time it takes for the star to complete an orbit, G is the universal gravitational constant, is the inclination of the orbital plane of the system with the line of sight of the observer and K_2 the radial velocity of the visible star. If we are interested in a lower limit for the mass of the compact object, not exactly its mass, then things are much simpler. The mass of the star M_2 can't be smaller than zero, neither the inclination angle can be higher than 90 degrees which implies that the mass of the compact object has to be necessarily bigger than the quantity that is left when we make i= 90º and M_2 =0, i.e.:

$$M_1 > \frac{PK_2^3}{2\pi G} = f(M)$$

This quantity, called the mass function f(M)is extremely important since it allows us to obtain in simple mode the indirect evidence for the existence of black holes. If f(M) is higher than 3 solar masses, the mass of the compact object will certainly be higher than this limiting value and, as we already discussed, a neutron star must have a limiting mass smaller than this value. So we can conclude that the compact object must be a black hole. It seems very paradoxical that one of the best pieces of evidences for the existence of one of the most exotic objects ever imagined by physicists, and the best example of the applicability of general relativity, comes from the application of simple Newtonian mechanics.

THE RADIAL VELOCITY OF THE STAR

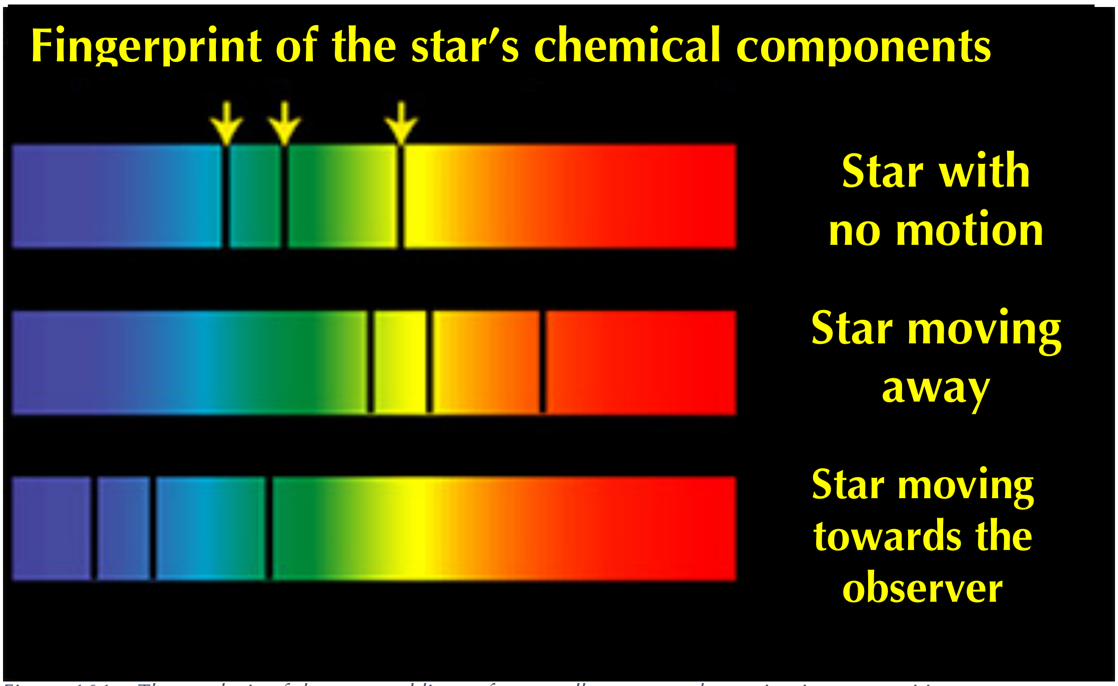


Figure 161 – The analysis of the spectral lines of a star allows us to determine its composition. When the star is moving the spectral lines appear to be shifted from the position they would have in a stationary reference frame. If the object is moving away from the observer the lines will appear to be shifted towards red. If the object is approaching the observer the lines will appear to be shifted towards the blue part of the electromagnetic spectrum. (Credit: NASA)

In order to calculate the mass function, besides the orbital period that can be easily determined by observing the visible star, we also need to know its radial velocity, the velocity in the direction of the observer. This can be determined by the Doppler effect: if an emitting source is moving, the wavelength of the signal , measured by an observer at rest, changes according to the velocity of the source (Figure 161). This effect explains why the whistle of a train (sound waves) acquire a lower pitch (a smaller wavelength) when it moves away. Although it is not possible to "listen" to the stars, the Doppler effect can be also applied. The light coming from stars is produced by nuclear reactions in their core having to cross the whole star before being released to space. A typical star like our Sun is fundamentally composed of hydrogen and small quantities of other elements such as helium, carbon, nitrogen, oxygen, etc. When the light goes through them, these elements absorb certain wavelengths depending on the element. As a result, the observed spectrum is full of lines. In the case of a binary system the star emits light (electromagnetic waves) and is orbiting a compact object. As a consequence of the Doppler effect, the spectra obtained by the observer on Earth, the spectral lines will appear shifted from their normal position depending on the velocity of the star in each point of its orbit. In summary, measuring the shift of the spectral lines is equivalent to measure the radial velocity of the star. In particular, the maximum radial velocity (K_2), reached by the star in the extremes of its orbit, is the parameter we need in order to calculate the mass function.

The mass function tells us that the mass of the compact object has to be bigger than a certain limit, which eventually is evidence for the existence of a stellar mass black hole, but it doesn't give us the mass of the black hole. In order to have such value we need the radial velocity of the star, and the mass of the companion star (M_2) and the inclination angle (i).

THE MASS OF THE COMPANION STAR

The determination of the mass of the companion star is relatively simple once we have its spectrum. Stars can be classified in different types according to their properties. Each type has a characteristic spectrum, i.e., the spectrum of a star tells us to which group the star belongs and therefore its mass.

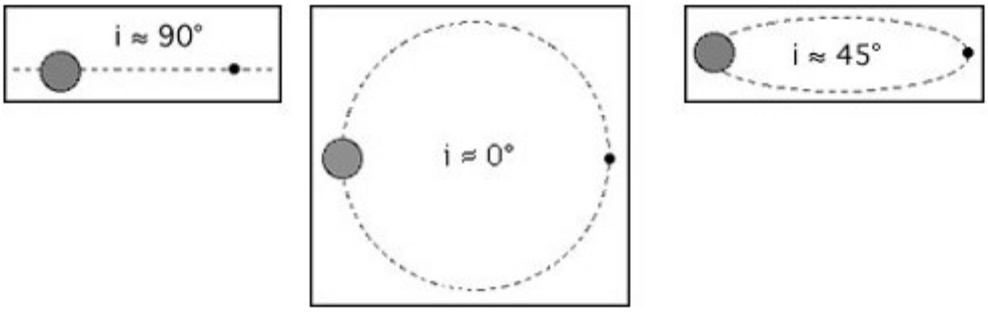


Figure 162 – The image to the left represents a binary system with an inclination angle of 90°. In this case, and because the companion star has the form of a pear, the resulting luminosity curve is a perfect ellipsoidal. In the image of the centre it is not possible to observe any variability since the star presents to the observer always the same surface. All other cases are more difficult to evaluate. For instance systems with an inclination of 45°. (Credit: Steven Degennaro)

Fortunately there is a way to know the inclination angle (Figure 162). As we saw previously, the low mass star fills its Roche lobe and assumes the shape of a pear. This will have as a consequence that the star will show to the observer different faces during its orbital movement, i.e., light coming from the star will appear modulated, with two maxima in brightness when the star presents itself to the observer sideways, i.e., the largest surface, and two minima when it presents the frontal and the posterior surface. Since this is an effect that depends only on the geometry of the binary system, the amplitude of the modulation, so called ellipsoidal modulation, depends strongly to the inclination angle (Figure 163).

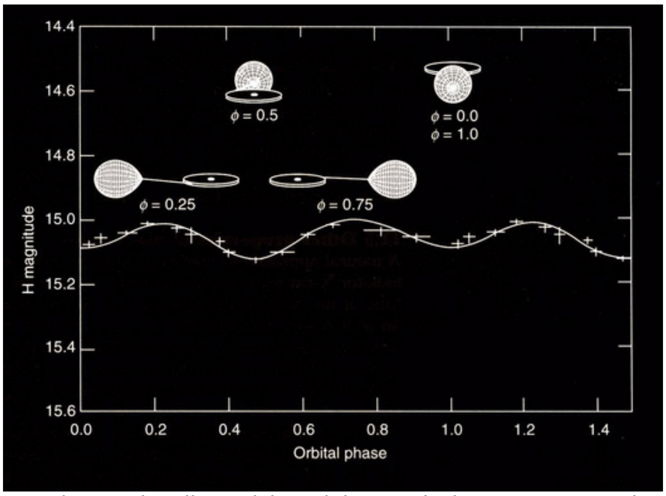


Figure 163 – This image depicts the ellipsoidal modulation of a binary system with an inclination of 40º. We can easily verify that the phases of higher luminosity are those in which the system is seen sideways. The orbital phase defines the position of the star in its orbit. For convention, we can this phase zero the one in which the star is in front of the disc presenting its posterior part to the observer. The crosses are real data from the Cen X-4 system. Comparing the real curve (the crosses) with the model (continuous line) we can measure the inclination angle. Cen X-4 is one of the few transient binaries that appear to have a neutron star and not a black hole. (Credit: T.Shahbaz

Knowing the luminosity of the star it is simple to create artificial ellipsoidal curves for all possible inclination angles. The comparison with the real curve (the crosses) obtained by the change in brightness of the star with the theoretical curves, gives us the measure for the inclination angle. Gathering all the information will lead us to the mass of the black hole candidate.

BLACK HOLES: ETERNAL CANDIDATES

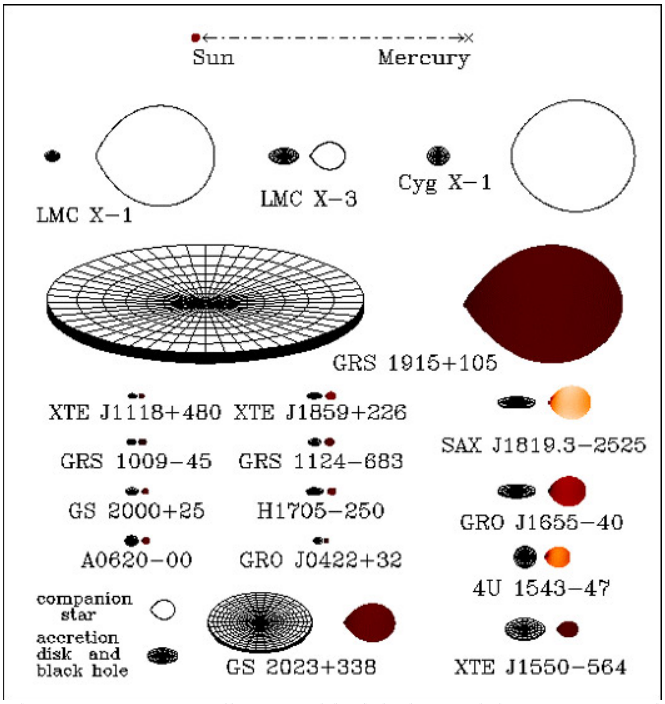


Figure 164 – This image depicts 17 strong stellar mass black hole candidates. Fourteen low mass and three high mass. (Credit: J. Orosz)

Even in the case where the mass is determined with good accuracy the object will still be called a black hole candidate (Figure 164). We have very strong evidence but not a definitive proof. We can only prove that in the particular region exists a compact object that will very likely be a black hole. However, the strong emission coming from the accretion disc doesn't allow us to observe the internal region. The compact object is completely unreachable. Some sceptical scientists for instance state that our knowledge about the equation of state of a neutron star is not yet enough to guarantee that they may not have more than 3 solar masses. But against this argument there is strong experimental evidence. All neutron stars we know so far have a mass smaller than 1.5 solar masses (Figure 165). However the object that we think can be a black hole may be something science has not predicted yet. The definitive proof would come if we could prove the existence of an event horizon, a unique characteristic of a black hole.

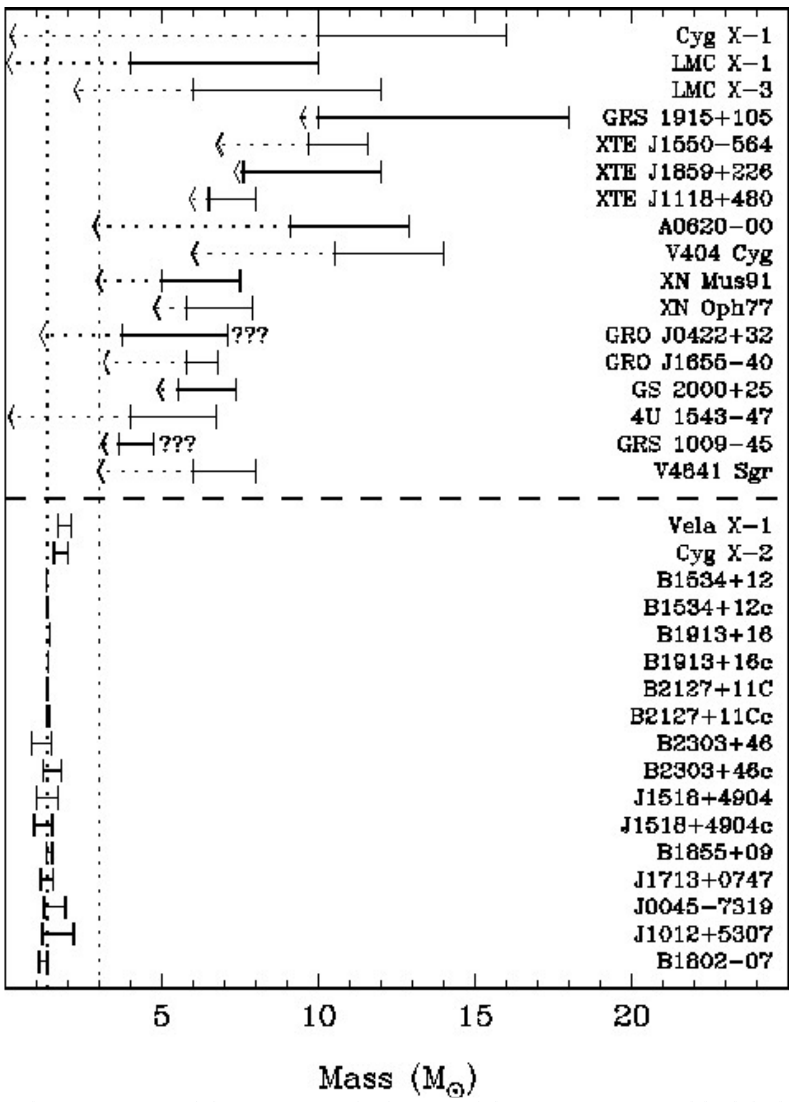


Figure 165 In the upper part of this image we find some of the most important black hole candidates and the indication of their masses. In the bottom part we can find the systems where the compact object is a neutron star. We can easily verify that in the last case the masses are all in an interval lower than 1.5 solar masses.

In the 90s, R. Narayan, made an interesting observation. For those systems that could be observed in quiescent phase, the X-ray emission of the black hole candidates was lower than the emission of the system containing neutron stars. This might be the solution. The explanation is very simple, if the gas coming from the accretion disc finds the surface of the neutron star, new reactions will take place as the radiation is re-emitted. If however there is an event horizon, than the gas will be forever lost. This characteristic will have as a consequence that neutron stars will emit more radiation, in the quiescent phase, than black hole candidates (Figure 166).

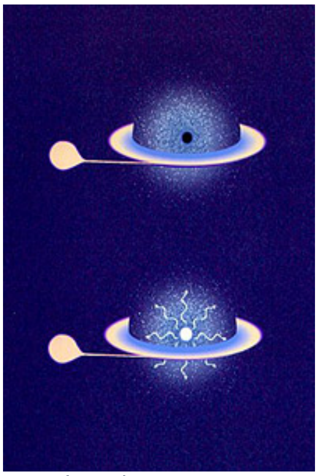


Figure 166 Artist's impression of two binary systems containing a compact object.
In the upper part the compact object is a black hole and in the bottom part a neutron star. The distinction between these two systems may be identified by observing their X-ray emission. Since a neutron star doesn't have an event horizon it will emit more radiation than a black hole. (Credit: Harvard Smithsonian Centre for Astrophysics)

The big problem is that the number of known systems is very low and thus a statistical analysis, that will allow us to reduce the error is yet not possible. What if the black hole doesn't belong to a binary system? Would it be possible to detect their existence? Black holes in the centre of galaxies don't belong to binary systems, how can we measure their mass? We will have the opportunity to explore this later.

SUPER AND MINI BLACK HOLES

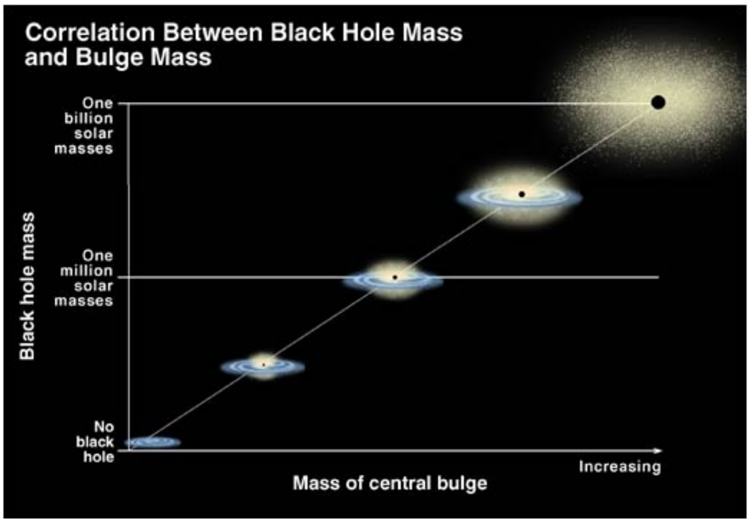


Figure 167 This image shows the correlation between the mass of the black hole and the mass of the central bulge of the Galaxy.
Studies in the last decade suggest that all galaxies might have a central black hole with masses that can reach billions of solar masses. (Credit: NASA)

Stellar mass black holes are miniature versions of the black holes existing in the centre of galaxies their difference being, as referred before, their mass. Some black holes mark their presence by being responsible for extremely energetic phenomena associated to quasars (active galactic nuclei that are at a great distance and thus in a far-off past) (Figure 167). Other black holes prefer to remain anonymous as for instance the black hole in the centre of our Galaxy, with a mass of approximately 4 million Suns and appearing to be in a calm phase. Its presence is inferred by the study of the trajectory of some stars around it, which can only be explained by the presence of a high mass object in the region. This region is called Sgr A*, first classified as a radio source in Sagittarius, as we can see in Figure 168.

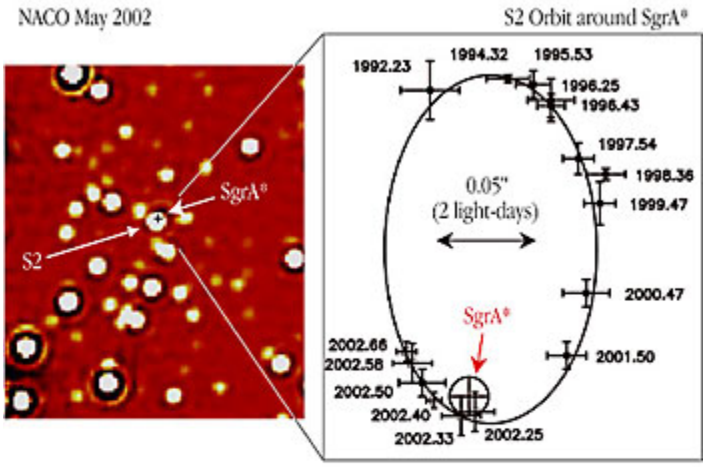


Figure 168 – Scheme of the trajectory of a star around what is likely to be the black hole in the centre of our Galaxy. Credit: ESO

If today we have a satisfactory theory for the formation of stellar mass black holes the same can't be said about these monsters that inhabit the centre of galaxies. Some scientists believe that they might have been the seeds that originated the galaxies. These black holes might have appeared in the early stages of our Universe and attracted matter existing around it, thus forming the galaxies. Other scientists believe that the chaotic movement of matter in the early stages of the formation of our Universe might have originated regions of greater density. These regions would be origins of galaxies. Under the action of their own gravity they contracted and attracted matter that was in the neighbourhood becoming bigger and bigger. This same process of contraction could have created black holes by forming more compact concentration of matter.

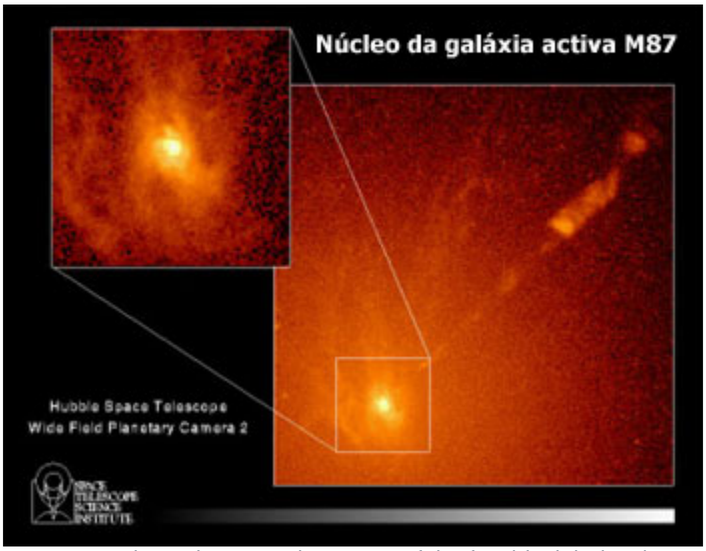


Figure 169 The Galaxy M87 hosts one of the first black holes discovered in the centre of a Galaxy, which might have billions of times the mass of our Sun. In the image we can see a zoom of the central region where the gigantic black hole might be hidden and the jet emitted with an extension of at least 5 000 light years.

The existence of black holes with huge masses started to be considered due to the discovery of quasars. Quasars are the farthest objects we can observe in the Universe. The fact that they are so far away and yet can be observed indicates that they are very bright sources: one quasar emits as much light as a thousand galaxies concentrated in a region equivalent to the Solar System. Another characteristic of quasars is that they present highly energetic jets of gas. There are also galaxies that have jets coming from their central region (Figure 169). The nuclei of these galaxies (the so called Active Galaxies) have properties very similar to the quasars. Since light travels with a finite velocity, an image of a quasar, when observed today, reveals what happened in a very remote past. Observing a quasar is the same as observing an epoch where galaxies were forming. In conclusion, astrophysicists think that quasars are in fact the nuclei of galaxies in an epoch where they were recently formed (Figure 170). Only phenomena associated with the presence of a black hole of high mass can explain the extreme luminosity of these objects.

Figure 170 Artistic view of the quasar ULAS J1342+09, is the furthest quasar observed up to today (Dec. 2017) in the observable Universe. Its spectral lines present a redshift of the order of 7.54, which means that its light took something like 13.1 billion light years ways to reach the Earth. Credit (ESO)

The origin of the radiation emitted by quasars (from their active galactic nuclei) is also related to the accretion of gas existing in the surrounding medium. The presence of high mass black holes in the central region causes the potential energy of the accreted gas to be transformed into electromagnetic energy. This process is enough to explain the high luminosity these objects have. The accreted gas also forms an accretion disc around the black hole as happens in X-ray binaries. In fact, scientists think that X-ray binaries and quasars are similar objects in different scales. Some low mass X-ray binaries exhibit similar behaviours than the far distant quasars and because of this they receive the name of microquasars. There are also high-mass microquasars e.g. Cyg X-1. In both cases the central compact object is believed to be a rotating black hole with an accretion disc and relativistic jet emissions can be observed, i.e., particles traveling with a speed close to the speed of light. The jets observed in micro-quasar may have an extension of some light years; in quasars this value goes to the value of millions of light years. The radiation coming from the accretion disc around a quasar or an active galactic nuclei is primarily in the ultraviolet and optical. But this is just redshifted X-rays. In the case of microquasars the predominant radiation is in X-rays.

The study of the dynamics of the gas surrounding the centre of the galaxies or the study of the dynamics of the stars originating the central region allows the determination of the mass of the central black hole with some precision.

There is yet another process in the Universe with behaviour similar to quasars and microquasars, the hypernovaes. It is a similar process to the explosion of a supernova, in which the progenitor star probably had high mass. In this case, strong gamma-ray emissions are observed associated to the final stage of the life of these stars. The remains of such stars will be a black hole surrounded by the material of the recently ejected star. In the accretion disc, and for reasons not yet fully understood, a jet of highly energetic particles may originate and by interacting with the expelled layers of the star will originate a phenomena known as Gamma-Ray Bursts (GRBs).

We already heard about stellar mass black holes with 5 – 20 solar masses and about black holes in the centre of galaxies with billions of times the mass of the Sun. Are there black holes with intermediate mass ? The theory of black holes studies so far puts no constraint on the size of the black holes. They can be gigantic as the now found in the centre of galaxies or as small as a particle. There is thus no reason for the nonexistence of the ones with intermediate size; the problem is how to detect them. The task is difficult but might not be impossible.

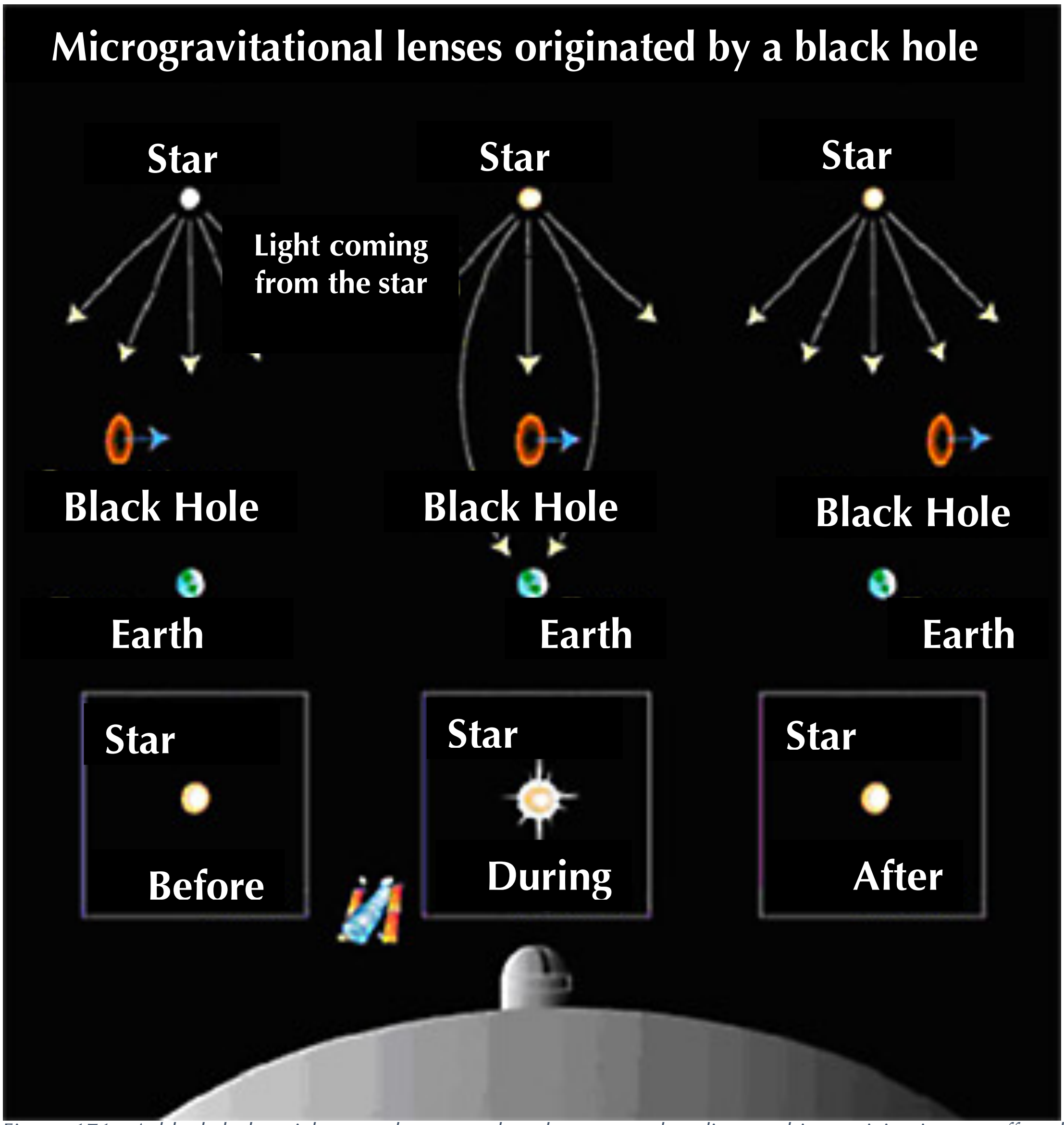


Figure 171 A black hole might pass between the observer and a distant object originating an effect known as "gravitational lenses". Credit: NASA.

The black hole acts as a magnifying lens increasing the luminosity of the object, in this specific illustration a star. Some of these objects may be lonely travellers in the Universe. This is the case of MACHOs (Massive Compact Halo Objects). These objects reveal their present via gravitational lenses effect, an effect predicted by Albert Einstein (Figure 171). So far only 3 black hole candidates were detected using this method with masses varying from 3 to 6 solar masses. But these are well within the stellar mass black holes mass range. What about intermediate masses?

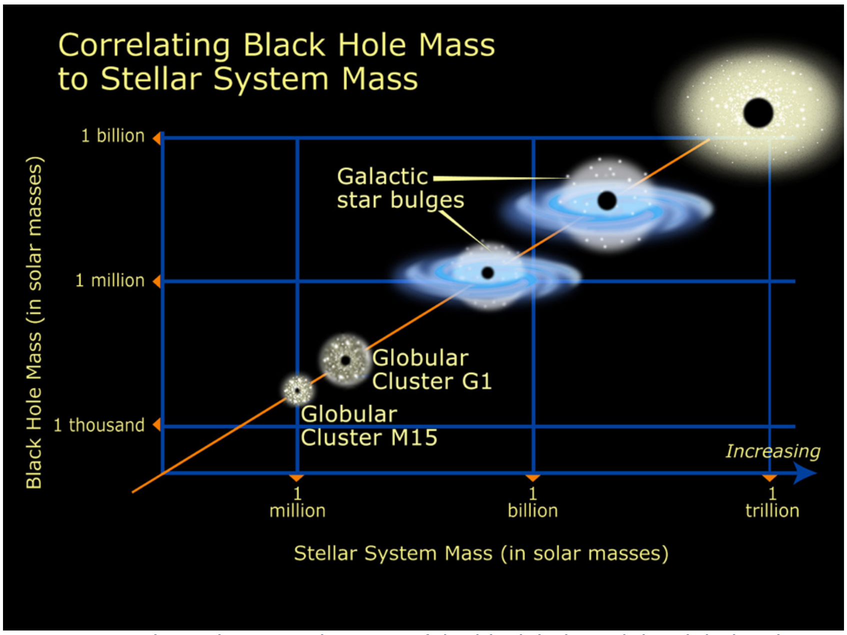


Figure 172 Relation between the mass of the black hole and the globular cluster.
Globular clusters contain the oldest stars in the Universe. If it is proved that they harbour black holes in their central region than they probably already had them when they formed.

Some of these objects have been discovered since the 90s. Some globular clusters, the case of M15 for instance, may host black holes with masses of the order of 4000 solar masses (Figure 172). Black hole candidates found in globular clusters seem to also have a direct relation with the mass of its host. It seems that there is an yet unknown mechanism that connects black holes to its host but the study of the behaviour of stars around the nuclei of the globular cluster might be indicators of the existence of a compact object (Figure 173).

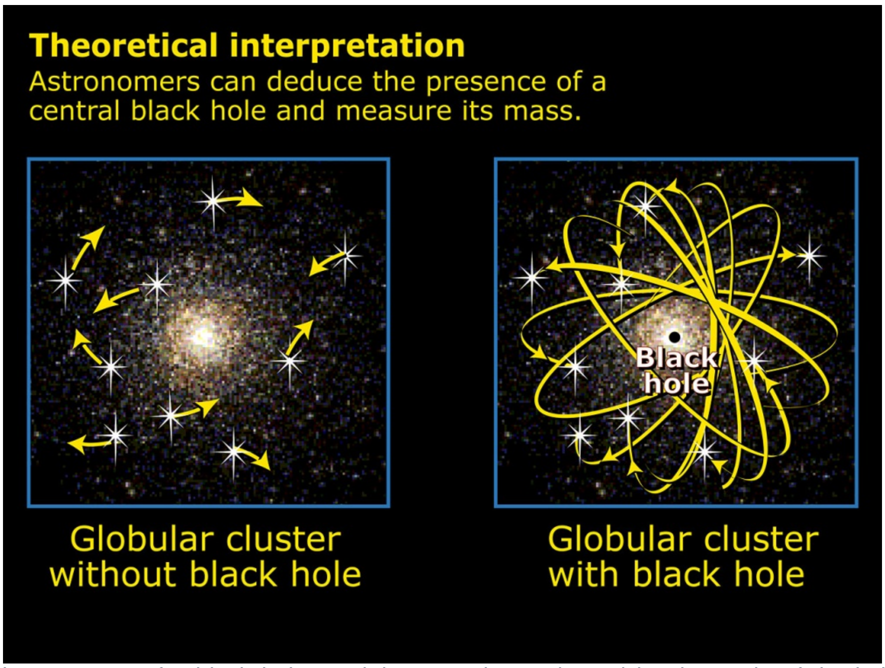


Figure 173 – The existence of a black hole candidate may be evidenced by the study of the behaviour of stars around the central nuclei. Credit: NASA

We know around 26 good black hole candidates in binary systems with masses up to a few tens solar masses; 4 candidates outside binary system also with small masses; around 10 with intermediate mass and 73 with masses that may go up to billions of solar masses. (August / 2014)
(http://blackholes.stardate.org/objects/type.php?p=stellar-mass)

But the story doesn't end here, there are still the mini black holes. These are the so called primordial black holes, predicted by Stephen Hawking and Brandon Carter in the 70s and should have appeared in the primordial Universe due to density fluctuations of matter filling the space-time. Some authors even make comparative studies between these mini black holes and exotic particles, finding interesting common factor between both. However there is no experimental evidence of their existence so far.

In the other extreme of our imagination are the "universal black holes". Some scientists believe that even our Universe may be inside one of these, or more correctly, in the interior of a white hole, an object that is exactly the same thing as black hole, but in this case, its event horizon is a place where everything can go out but nothing can come in.

Black holes are everywhere and in fact we know very little about their mysterious existence. They seem to exist from small to big scales, in different theories and predictions are that our own Universe will someday end up in a vast, dark emptiness filled with nothing but black holes.

Original text based on:

http://www.portaldoastronomo.org/tema.php?id=7

(by Cristina Zurita and Rosa Doran)

(reviewed with the support of Fraser Lewis- Faulkes Telescope Educational Program)

OBSERVING STELLAR BLACK HOLES CANDIDATES

Learning outcomes

At the end of this module participants should know the procedure used to identify black hole candidates and how to determine the limiting mass of a compact object in a binary system.

Rationale

This module introduces participants to the technique used to determine the limiting mass of a compact companion to a visible star.

Resources

Set of images of black hole candidates
Salsa J
Excel

Eclipsing Binary Stars

The most common stellar black hole candidates live in binary systems where one of the components is a compact object and the other an observable star. The light curve of a binary system allows us to study the different components (Figure 174). Take for instance the example below:

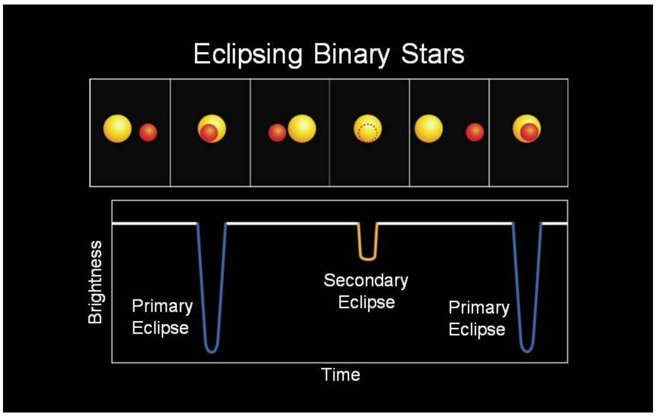


Figure 174 Light curve of binary star Kepler-16 (Credit: NASA)

In the case where one of the components is a compact object we only see the visible star. As explained before, in particular in the case of the low mass x-ray binaries, this stars fill their Roche Lobe and therefore acquire a pear shape.

As they orbit the compact companion different parts are visible to us and depending on the inclination of the system a limit on the mass of the compact object can be established

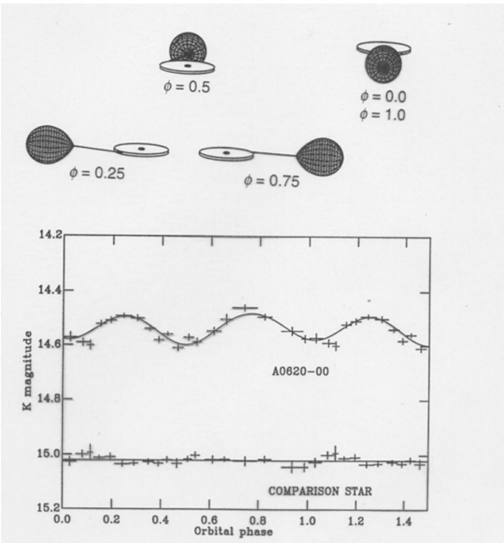


Figure 175 Light curve of the A0620-00 (a binary system where the compact object is a strong black hole candidate). Credit: Shahbaz et al, 1994.

The image in Figure 175 shows the light curve of the black hole candidate A0620-00. Depending on the position of the companion star and the compact object, with its accretion disc, we see different brightness coming towards the observer. Remember that we don't see the components; we only observe a dot which brightness changes in time. It is from the study of this changes, the study of the light curve of the system, that we can infer its characteristics.

FINDING THE MINIMUM MASS FOR THE BLACK HOLE CANDIDATE XTE J1118+480

The object we will study is the black hole candidate XTE J1118+480. It was discovered in March 2000 by the Rossi X-ray Timing Explorer satellite. It is approximately 6 000 light-years away in the constellation of Ursa Major (Figure 176).

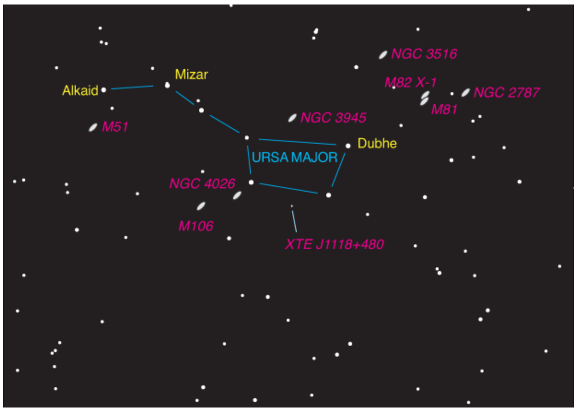


Figure 176 Location of the black hole candidate XTE J1118+480 (Credit: Black Hole Encyclopedia)

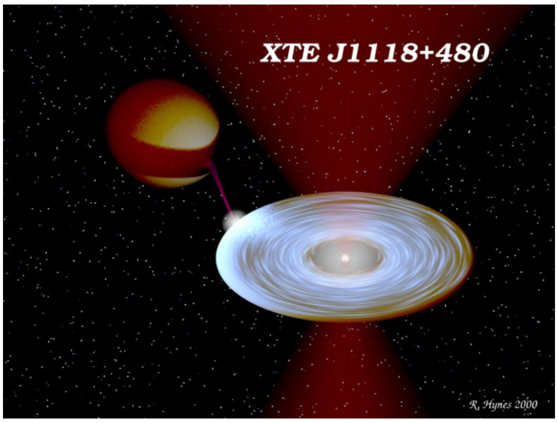


Figure 177 Artist impression of the binary system XTE J1118+480. Credit: R.Hynes

The system is composed of a compact object, and a low mass star. The compact object is pulling matter from the companion star and the phenomena taking place in the accretion disc helped discover this object when it entered into transient phase (Figure 177).

This system already appeared in old images (over 40 years old) and it seems to exhibit a looping path that takes in out of the disc of our galaxy (Figure 178). Studies of this trajectory indicate that the object might have been inside of a globular cluster and was probably kicked out after the supernova explosion of the progenitor star that gave birth to the compact object. The estimate of the mass of this black hole candidate is of the order of 7 solar masses. This is precisely what we want to confirm with this exercise.

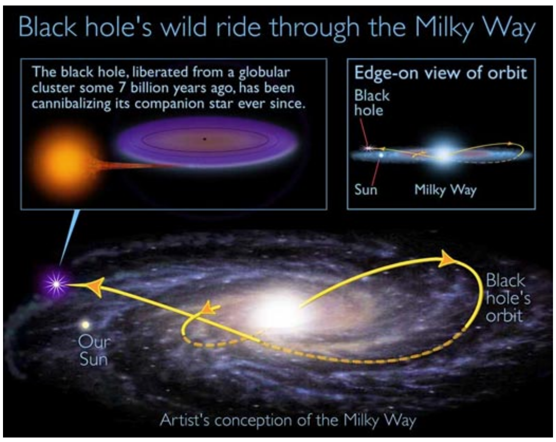


Figure 178 Artist impression of the path of the XTEJ1118+480 through the disc of our galaxy. Credit: STScI

The data we will analyse is a time sequence of 62 images obtained by Faulkes Telescope North taken on 13/05/2009. We will analyse these images using salsa J and excel.

The data are a temporal series of 62 images showing several stars surrounding the object we wish to study (Figure 179). We will select some of these stars to be comparison stars in our study (stars marked as 1, 2 and 3). The procedure is to make photometric measurements of all the comparison stars and the black hole candidate for all the images. The flux of the comparison stars should remain constant (considering the noise level) as a function of time while the flux of the binary system containing the black hole candidate shall vary (marked with a cross). By plotting the flux versus time we shall see the variation and proceed to estimate the mass of the non-visible compact object.

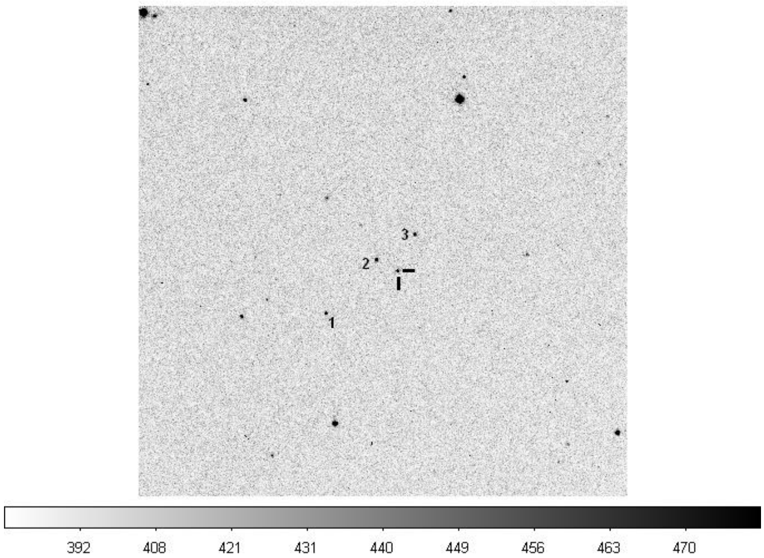
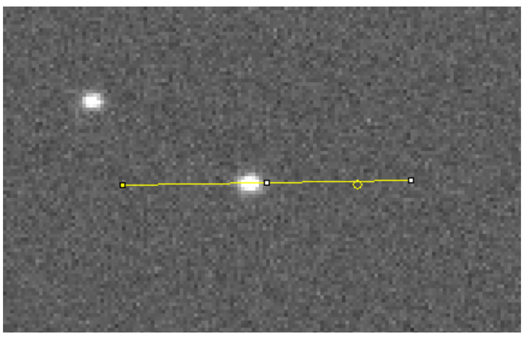
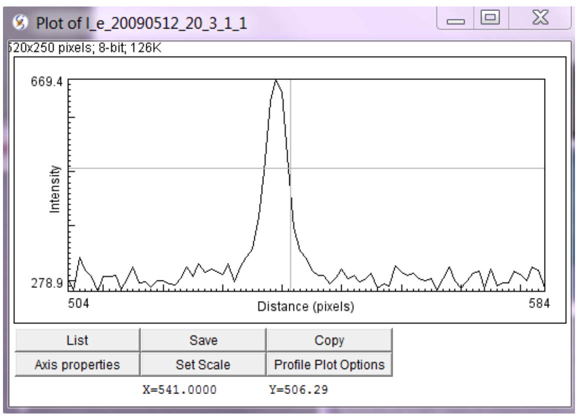


Figure 179 The finding chart (the map of stars locating the object and the comparison stars)

The procedure to determine the best aperture value to be used when analysing the images is followed.





In practice, a good choice for the radius of an *aperture* is about 1.5 or 2.0 times the *FWHM*. In the examples below the value used was 6 pixels for the aperture radius.

Now you can start to measure the intensity for the 3 comparison stars and for the black hole candidate. Make the measurements in all the images for each star at a time so you can have a column for the values of each object separately. Since the images are big the suggestion is to make the measurements to 20 images at a time. Or, and this is in fact the main objective, you can distribute the images through a group of students and group the results later, provided they use the same aperture radius and the same comparison stars. You can choose to tile them which will make it easier to perform the procedure. But make sure you follow the order of the pictures. Which is easy if you follow their number. The automatic tile procedure of Salsa J doesn't respect the numerical order

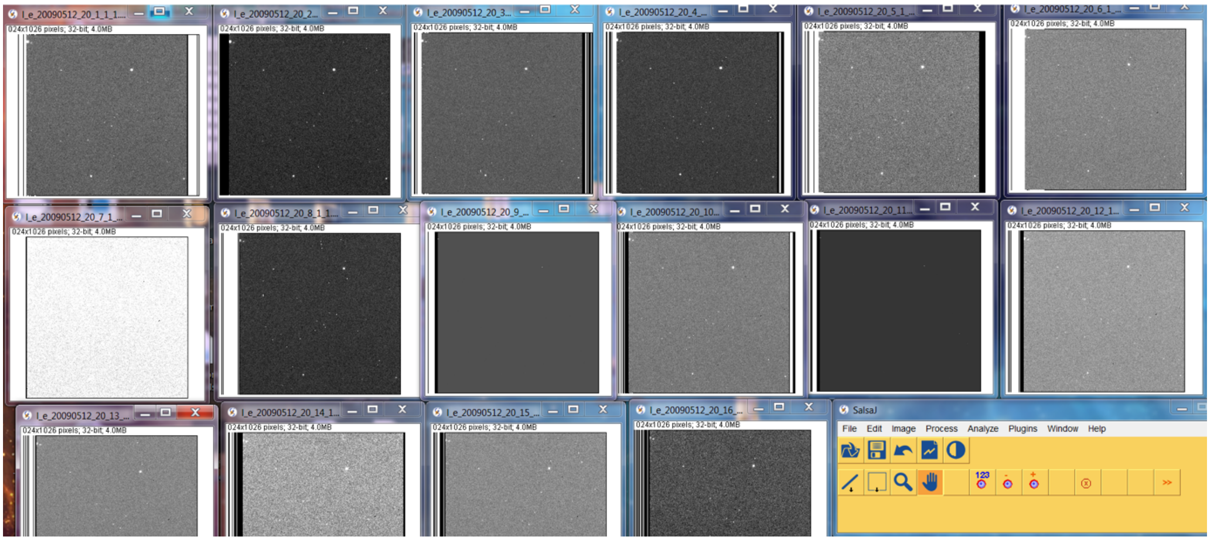
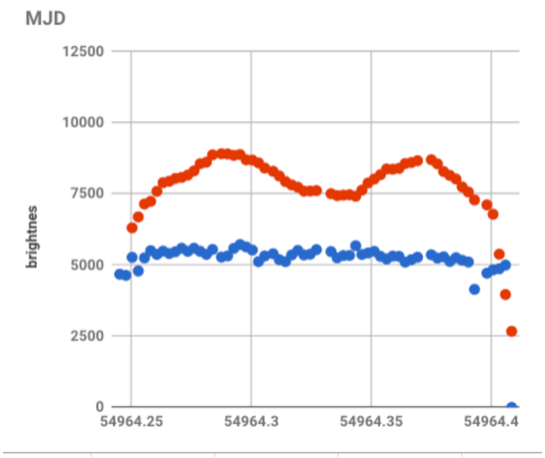


Figure 180 Selection of 20 images, tiled and then reordered

Make sure you adjust the brightness and contrast in all images in order to be able to see all the objects. If you can't see them don't use that particular image. Sometimes if you close and reopen the image the brightness and contrast appear better. Since we will be working with relative magnitudes, where we are comparing intensities of the comparison stars and the black hole candidate we don't have to worry about absolute magnitudes and standard stars etc. We are not looking for the absolute value of the magnitude of the object but the variations to its intensity. You will also need the Modified Julian Date (MJD) date for each image. You find this information in the header of FTS images. In Salsa J you select the "show info" under the image menu and in the header you will find the value for MJD. This is the value to be used on the x-axis

The plot of the brightness of the selected object and the average of the comparison stars should look like this:



From this graph we can clearly see that our target varies far more than the comparison stars.

We know that the orbit of the visible star around the compact object is periodic and the set of images above have been taken continuously during one night allowing for a full period to be captured.

Finding the orbital period is complicated and time demanding. But we can make a rough estimate from the graph above since it is showing evidence that the whole period is in the set of images. We can try to adapt the value of the period that best fit our purposes. Your students can play a bit with the value of the period and try to find the best fit. A nice tutorial on the calculation of periodicity and determination of phase in variable systems can be found here: http://www.aavso.org/files/Chapter12.pdf

Scientists already know the period of this object P= 4.08 hrs = 0.17 days. (http://adsabs.harvard.edu/abs/2001ApJ...556...42W)

Using the formula to determine the limit mass of the compact object

$$f(M) = \frac{{M_1}^3 \sin i^3}{(M_2 + M_1)^2} = \frac{P{K_2}^3}{2\pi G}$$

(where M_1 and M_2 are the masses of the compact object and the companion star respectively, P the orbital period, i.e., the time it takes for the star to complete an orbit, G is the universal gravitational constant, i is the inclination of the orbital plane of the system with the line of sight of the observer and K_2 the radial velocity of the visible star)
The radial velocity of the visible component of this system was determined to be ~ 700 km s^{-1} , (http://adsabs.harvard.edu/abs/2001ApJ...556...42W).

The period in seconds = 0.17 * 24*60*60= 14 688 (**this should be determined by the students**). The data range from (MJD = 54964.24506 to MJD= 54964.40856) which is almost a full period of (0.1635).

Assuming all the known values retrieved from radial velocity measurements we end up with the following value for the limit mass of this black hole candidate (http://arxiv.org/pdf/astro-ph/0104032.pdf):

$$f(M) = \frac{{M_1}^3 \sin i^3}{(M_2 + M_1)^2} = \frac{14\,688\, s * 700^3 * 10^9 m^3\, s^{-3}}{2\pi\, x\, 6.67384 *\ 10^{-11} \mathrm{m}^3\, \mathrm{kg}^{-1}\, \mathrm{s}^{-2}}$$

Msol = 1.9891 × 10^{30} kg

$$f(M) = \frac{{M_1}^3 \sin i^3}{(M_2 + M_1)^2} = 1.2 * 10^{31}\, kg \sim 6.1\, Msol$$

Using the period retrieved by the students will enable students to get an approximate values for the mass of the stellar black hole candidate XTE J1118+480.

Appendix X A Black Hole Lurked at the Centre of our Galaxy

This exercise was developed in the framework of the project Discover the Cosmos (Rockstroh, Doran, 2012a). The exercise was adapted to the inquiry based methodology by NUCLIO using the original exercise created in the framework of the project European Hands-on Universe (Authors Translation to English & adaptation: Olivier Marco
Original idea: Pachomius Delva & Jean-Christophe Mauduit)

Name of the Institution: NUCLIO / IAP

Title of the educational scenario: A black hole lurked at the centre of our Galaxy

EDUCATIONAL PROBLEM:

Teaching about the Universe involves describing extraordinary objects that have little in common with our daily life. Students are introduced to a whole new world of phenomena that they had no idea could exist. Students may get engaged in the subject, but the traditional textbook based instruction does not meet the expectation of the students, since these are theoretical and abstract ideas that they are required to accept and learn. They are shown beautiful pictures, but the essence of the subject is skipped: how are those pictures taken? what do those colours represent? what phenomena are occurring? how do we know so much about objects that lie so distant? It is not easy for teachers to use infrastructures that allow them to explore the subject on a more realistic manner – for instance, how can they "show" their students a black hole?
On this particular subject, black holes, students usually have the idea that since a black hole does not emit light, it cannot be detected. But books talk about black holes as a sure thing – so how do scientists infer the existence of a black hole? It is also frequent for students to think about a black hole as an entity that will swallow everything around it – so they think that the whole universe will end up being pulled into a black hole.
Another common educational problem is that students tend to separate science subjects in a way that they do not associate Astronomy with Physics. They have difficulties in applying what they learn in Mechanics, for example, to the motions in the sky. Moreover, they might have doubts in applying the same laws to astronomical situations as the ones they apply here on earth.

EDUCATIONAL SCENARIO OBJECTIVES:

Within this scenario, students will apply their knowledge on Mechanics (Kepler's Laws, Newton's Laws) to a specific astronomy problem and will have the means to infer the location of a black hole candidate.
Students will be shown the motion of stars in the centre of the Milky Way and asked to conduct their own research to understand what they are observing. During the scenario the students will assume the role of a scientist, work with real data from scientific telescopes (astronomical images) and real scientific software for data analysis (SalsaJ), thus gaining a first-hand experience of scientific research. They will be guided in order to comply with the following steps:

- design and conduct the investigation;
- formulate and revise scientific explanations and models using their knowledge and the observations;
- recognise and analyse alternative explanations and models;

- communicate and defend a conclusion(s).

Experiencing this scenario, students should acquire a feeling of accomplishment, as they started from “raw” information and were able to infer a black hole lurked at the centre of our Galaxy! This satisfaction should help them gain an appreciation and joy for scientific research, thus helping many of them consider a scientific career.

CHARACTERISTICS AND NEEDS OF STUDENTS:

Students have been showing a growing difficulty in learning Mathematics and Science subjects, side by side with a growing lack of interest in choosing a scientific career. Despite their attraction to technology devices, they see science as uninteresting, distant and boring.
The age of students for this scenario is 15 to 18 years old.
Students need to:

- develop abilities necessary to do scientific inquiry
- develop understandings about scientific inquiry
- identify questions and concepts that guide scientific investigations
- design and conduct scientific investigations
- use technology and mathematics to improve investigations and communications
- formulate and revise scientific explanations and models using logic and evidence
- recognize and analyse alternative explanations and models
- communicate and defend a scientific argument

EDUCATIONAL APPROACH OF THE EDUCATIONAL SCENARIO TEMPLATE

Description of the Educational Approach rationale

This scenario is structured upon the phases prescribed for inquiry-based learning and allows students to make their own discoveries, albeit in a structured and guided way. This approach is an iterative process of (1) question eliciting activities, (2) active investigation by students, (3) creation, these are (4) discussed already at early stages of the process, leading to (5) reflection about knowledge and the learning process, which in turn leads to new and refined questions (1) and the process goes on for another cycle.

LEARNING ACTIVITIES:

Phase 1: Question Eliciting activities

You may begin your lesson by talking about ESO and the Very Large Telescope (VLT), showing images and videos from
http://www.eso.org/public/teles-instr/vlt.html
You can tell the students that they will use images from this telescope – one of the best of the world - for their project. They should be aware that they will use images that professional astronomers use for their scientific work, namely, to study the centre of our Galaxy.
They should then download the images from

http://www.euhou.net/docupload/files/Exercises/BlackHole/blackholeimages.zip

and uncompress the zip file on their computer.

Open SalsaJ software (version 2.2) and click on **Files**; navigate to the place where the uncompressed folder is stored and then open all the fts files (FITS files).

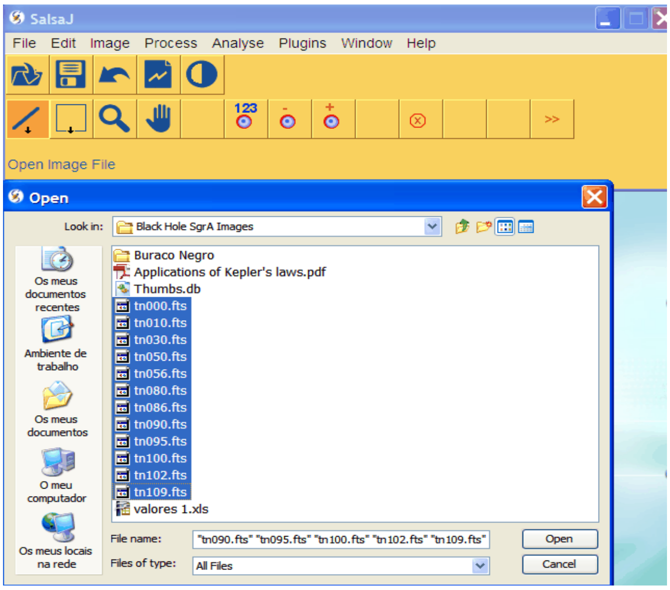


Figure 181 How to open a file in Salsa J

Click on **Window** then on **Tile**

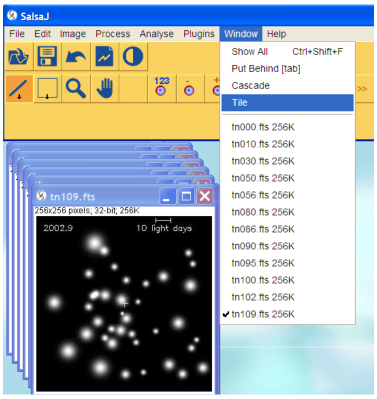


Figure 182 How to tile windows using Salsa J

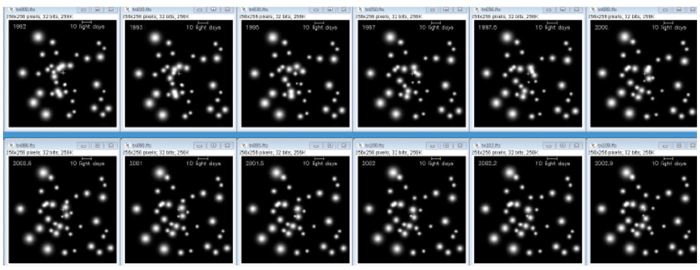


Figure 183 View of tiled windows

Click on **Image**, then on **Stacks**, then on **Images to Stack**

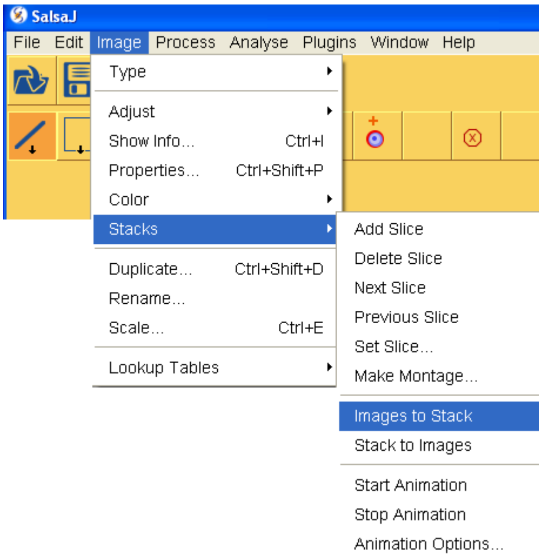


Figure 184 How to stack images to produce a movie using Salsa J

Click again on **Image**, then on **Stacks**, then on **Start animation**. (To make the image bigger click on the **magnifier** and then on the image)
The students will now see the animation showing the motion of the stars in the centre of the Milky Way.
Discuss what is happening with your students, making sure they talk about Kepler's laws, planetary orbits and ellipses.
You can now show them the following movies and animations:
http://science.discovery.com/videos/through-the-wormhole-black-hole-in-the-milky-way.html
http://hubblesite.org/explore_astronomy/black_holes/home.html
http://chandra.harvard.edu/resources/animations/blackholes.html

and have them read a brief introduction to the research topic.
Introduction to the research topic: Galaxies and Black Holes
Black holes are objects from which not even light can escape. Black holes cannot directly be seen. One can infer their presence by searching for the gravitational influence they impose on nearby objects, namely stars. Observations have been done over almost 20 years, with the most powerful telescopes, including a "laser star" in a very "Star Wars" style...
This exercise allows, through the analysis of images of the Galactic Centre, the measurement of the mass of the supermassive black hole. By following the movement of a star, and thanks to Kepler's laws, the pupils will get a result comparable with the latest scientific value. They will come to appreciate the limitations of the method and results.

A LITTLE BIT OF HISTORY

The idea of "black hole" was already mentioned by John Mitchell and Pierre-Simon de Laplace in 1796. The later wrote in his Exposition du Système du Monde ("*The System of the World*").

"He pointed out that there could be massive stars whose gravity is so great that not even light could escape from their surface – prevent its rays of light from reaching us. It is thus possible for the biggest bright bodies of the universe to look invisible to us."

At that time, astronomers did not take this idea seriously, because they didn't have theories satisfactory enough to describe and understand these new celestial bodies.

With General Relativity – a theory proposed by A. Einstein in the beginning of the XXth century – astrophysicists found a good description of what a black hole could be and its origin.

Recently, technical developments in image detectors, mainly in the infrared domain, have enabled us to see the centre of our Galaxy, hidden (in the optical) in huge amounts of dust. Thus astrophysicists were able to infer the existence of a "super massive" black hole. Studying how stars move around the Galactic centre gives the possibility to know the mass of this black hole. This is the goal of this practical exercise.

Black holes are mysterious objects, whose existence has not been definitively proven. Therefore, if we want to be rigorous, we should always call them black holes "candidates". Due to their strong gravitational field, they are one of the best examples of the applicability and importance of the General Theory of Relativity.

Although mysterious, black holes are the simplest entities of our Universe. They can be completely characterized by only three parameters: charge, mass and angular momentum. This means that black holes at the centre of galaxies and stellar black holes have one major difference: their mass!

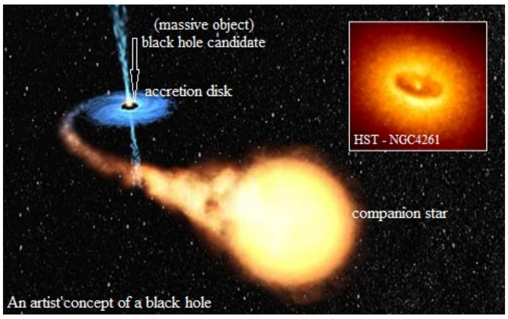


Figure 185 Artistic view of a stellar mass black hole candidate Credits: lasers.llnl.gov

The stellar black holes are a miniature version of black holes that are believed to exist in the centres of galaxies. They are formed at the end stage of the life of a massive star.
Despite the fact that their major characteristic is that they don't emit light, galactic black holes, are responsible for some of the most energetic phenomena in the Universe. During their active phase, probably associated with a higher rate of matter accretion, the region surrounding them is very bright and can be seen from far distances. The host galaxies are then called Active Galactic Nuclei.
The black hole at the centre of our Galaxy appears to be in a calm phase, and has approximately 4 million times the mass of the Sun. Its presence is betrayed by studying the trajectory of some stars that can only be explained by the presence of a massive object in that region.

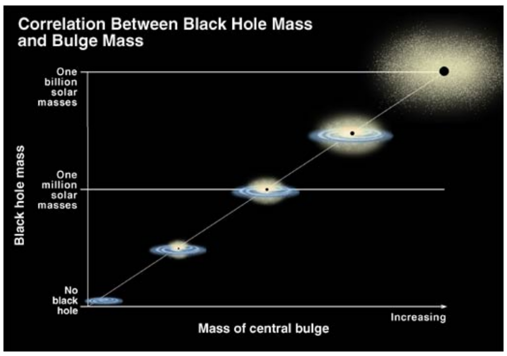


Figure 186 Graphic showing the correlation between Black Hole Mass and Galaxies Bulge Mass -- Credit: NASA

Most galaxies are believed to host black holes and their size, and the black hole size are directly related.
The Milky Way, the whitish lane that can be observed in a dark starry sky, is our Galaxy. It is composed by approximately 300 billion stars and numerous clouds of gas and dust. Its shape is a disk – approximately 80,000 light-years in diameter – with a bulge in its centre which can be considered as the nucleus of our Galaxy. All this can be seen on the illustration below:

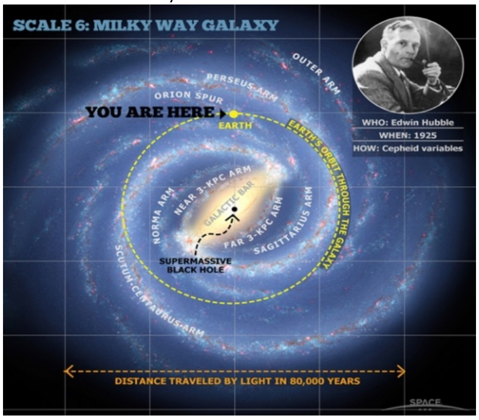


Figure 187 Milky Way Galaxy Map - Credit: NASA

The Solar System, where the Earth is located, revolves on the outskirts of the Galaxy around the nucleus. Many clouds of gas and dust between us and the nucleus have long prevented its direct observation. Recently, with high resolution infrared cameras, one could directly observe the motion of stars near the Galactic Centre, as shown in the picture below.

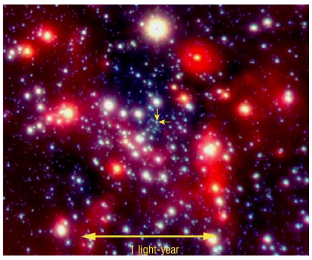


Figure 188 Motion of Stars near the centre of our galaxy Credit:ESO

Another unit of distance that will be handy in this exercise is the light-day, which is the distance travelled by light during a day, i.e. $2.59*10^{13}$ meters. One can see, on the previous picture, that the stars closest to the galactic centre are less than one light-year from it.

Figure 189 Johannes Kepler

Johannes Kepler (1571-1630) was a German astronomer that postulated three laws that characterize the orbit of a planet around the Sun. The first law states that the trajectories of planets are not circles but ellipses. An ellipse is drawn on the diagram below:

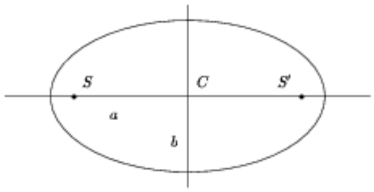


Figure 190 First Kepler Law

It is characterized by a, length of its semi-major axis, the length, b, of its semi-minor axis, the two foci, S and S', and its centre, C. The third law states that when the square of the period, T, of a planet (the time it takes for a ride around the sun) is directly proportional to the cube of the semi-major axis, a, of the elliptical orbit of the planet:

a^3 / T^2 = constant

PHASE 2: ACTIVE INVESTIGATION

PROPOSE PRELIMINARY EXPLANATIONS OR HYPOTHESES

In order to observe with more detail the movie, it can be slowed down (e.g. 1 image per second):

- click on **Image**, then on **Stacks**, then on **Animation Options** and chose **speed**: 1 image second;
- click on **Image**, then on **Stack**, then on **Stop Animation**;
- click on **Image**, then on **Stack**, then on **Stack to Images**;
- click on **Window** then on **Tile**; you can see again the 12 photographs of the same area in the sky, showing the centre of the Milky Way.

Students should now be invited to propose explanations to the observed motion of the stars.

PLAN AND CONDUCT SIMPLE INVESTIGATION

Students will conclude that they have to study the orbit of the stars in the centre of the Milky Way. That can be done by determining the elliptical orbit of the stars.

Choose star S2 (photo below).

Click on **Plugins**, then on **Macros**, then on **Install.**

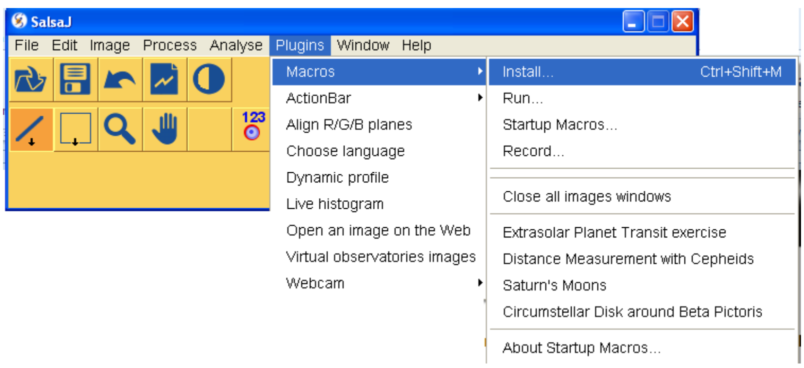


Figure 191 Depiction of the Reference Star

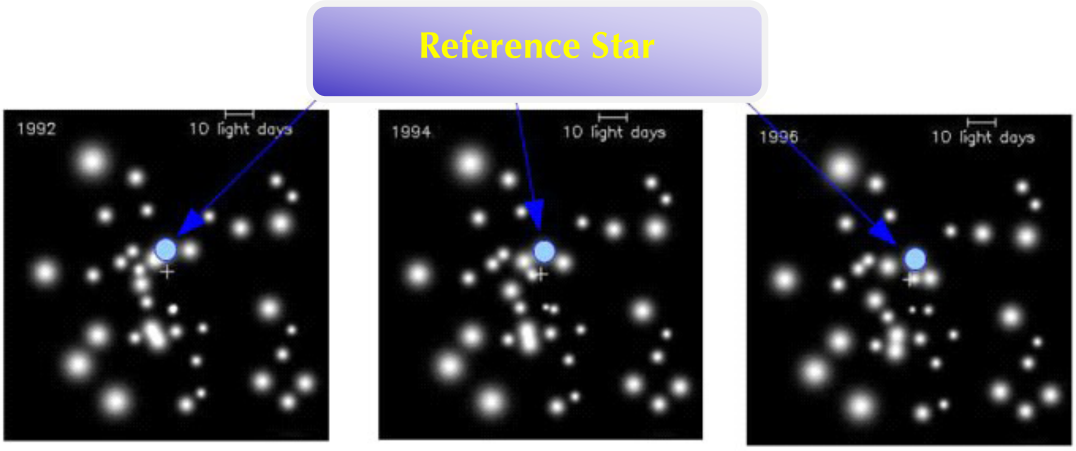
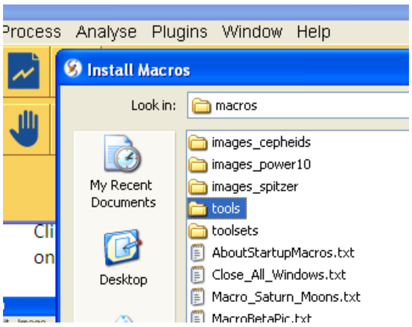


Figure 192 Instructions to install a Macro

Then on the folder **tools** select **PixelPicker Tool** then finally on **open**



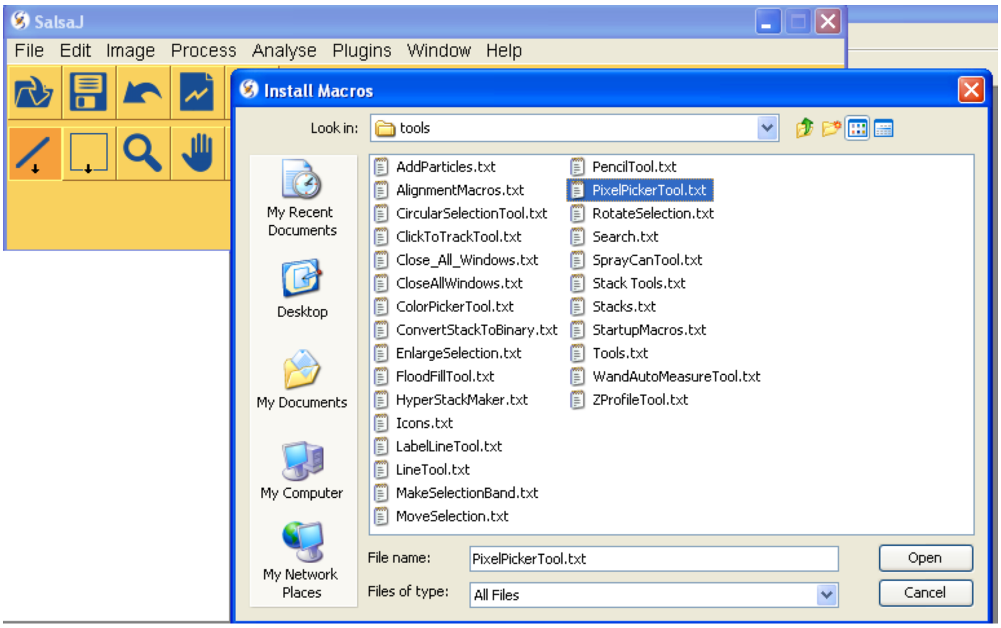


Figure 193 Instructions to open the Pixel Picker Tool

The **Pixel Picker Tool** can then be accessed on the second row of icons of the main window of SalsaJ. It's the icon with a simple dot. Click on the star S2 using this tool in the 12 consecutive photographs and note its coordinates in the popup window: for a better precision, you can use the "Zoom" function of SalsaJ.

As an alternative to this tool, you can simply hover the mouse pointer on the star and check the coordinates on the lower left corner of the SalsaJ main window.

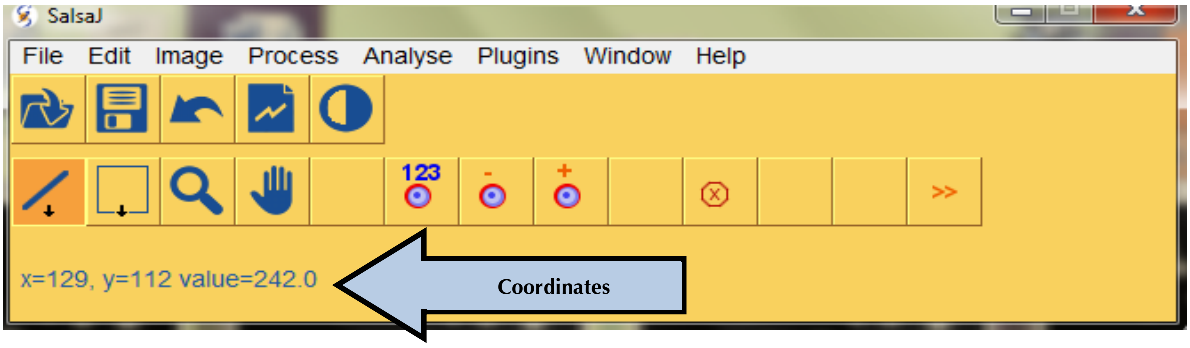


Figure 194 How to find the current coordinates in an image with Salsa J

Another option is using the **Photometry** button ()

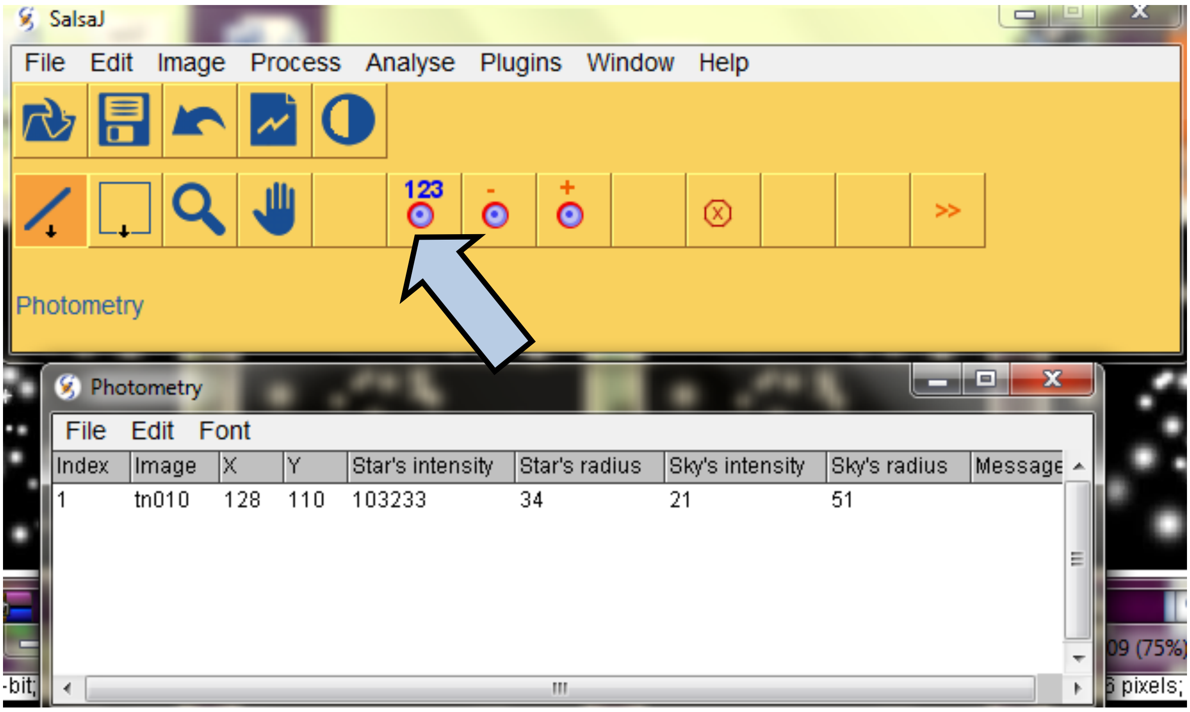


Figure 195 Using the photometry tool using Salsa J

To reduce the star radius measurement, select **Analyse**, then **Photometry Settings**, and then **Forced Star Radius** and select a value. The objective here is to make the program select one single star.

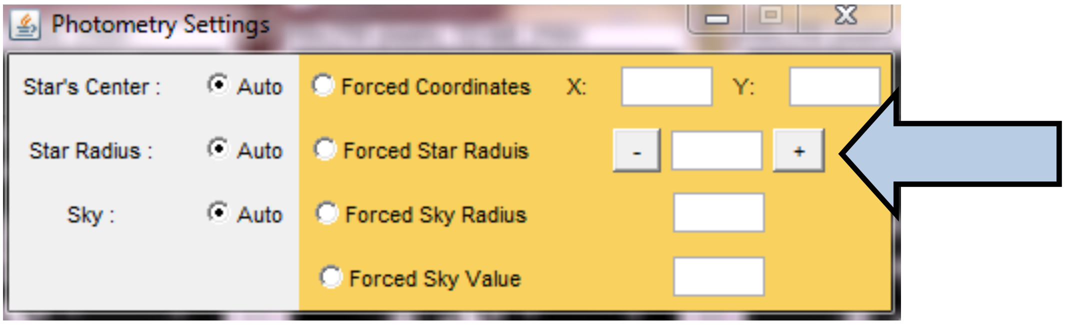


Figure 196 Photometry Settings Window

Year	1992	1993	1995	1997	1997,6	2000	2006,6	2001	2001,5	2002	2002,2	2002,9
X (pixels)												
Y (pixels)												

Fill in the following table with the S2 star coordinates (x,y)

Using Microsoft Excel:

- Open Microsoft Excel.
- Copy the line X in column A and the line Y in column B.
- Select the two columns and select **Insert**, then **Scatter**, you just draw a graph with these points.
- Join the points on the graph and note an approximately elliptical form: identify the major and minor axes of this ellipse.
- Stretch the graph vertically so that the scale on both axes is the same.
- Click **Insert**, then **Forms** and select an **ellipse**.

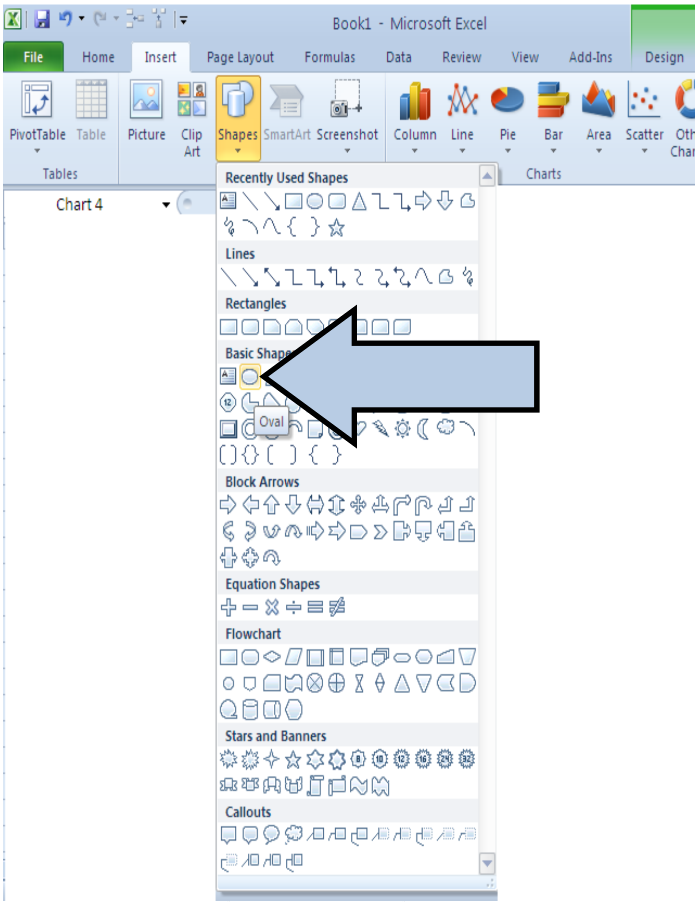


Figure 197 Inserting Elipses Using Excel

- If the ellipse is filled inside, press the right button of the mouse and select **Format Shape**, then select **No Fill**. Try to fit as many points as possible with the ellipse by varying the width and height. If your graph doesn't look like an ellipse, make sure that the scale on both axes is the same.

- Measure the length of the major axis (2*a). To make a more accurate determination of the major axis length, select the x-axis and with the right button of the mouse select **Add Minor Gridlines**. Repeat the same procedure for the y-axis.

  - ΔX = ____ pixels ΔY = ____ pixels

- Using Pythagorean Theorem:

  2*a = ____ pixels

PHASE 3: CREATION

GATHER EVIDENCE FROM OBSERVATION

With all the information at hand students will now proceed and measure the mass of the black hole at the centre of the Milkyway.

Value of the semi major axis in light days

- Return to SalsaJ, select an image and see the scale found in the upper right corner of it.
- Select **Straight line** and measure the length of the scale (in pixels) which is in the upper right corner of the image.

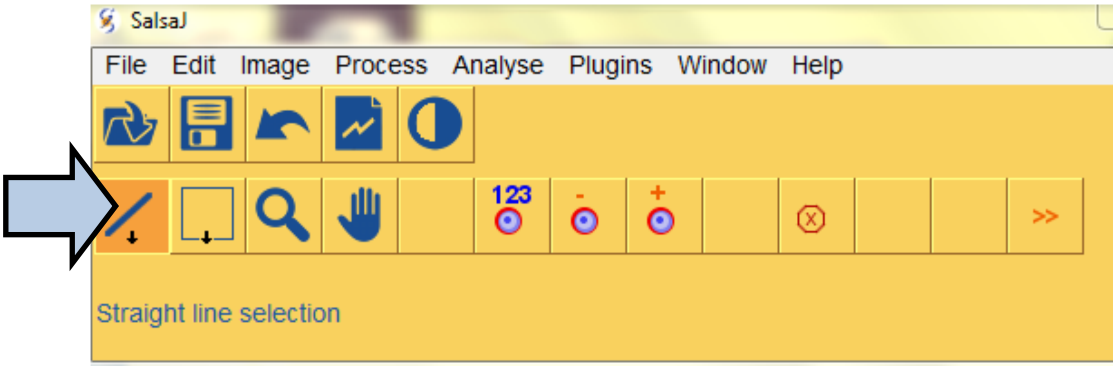


Figure 198 Drawing a straight line using Salsa J

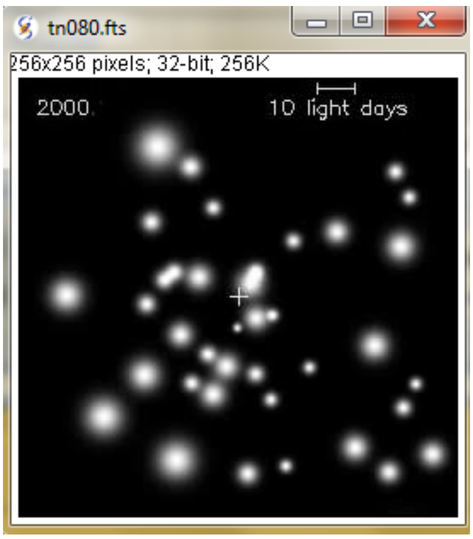


Figure 199 View of the stars at the centre of our galaxy

10 light-days = x pixels

- Convert the value of **a** to light-day: 2*a = ___ light-day
- Find out the value of the semi-axes “**a**”: a = ___ light-day

- Find out the distance between 2 pixels, first in light-days, then in meters.
- Deduce from the previous question the value of the <u>semi major axis</u>, **a**, and the <u>semi minor axis</u>, **b**, of S2's orbit.
- Using the previous Excel graph, the first Kepler's law and the relation

$$\mathbf{c = (a^2 - b^2)1/2 \ ,}$$

determine the position of the celestial body (Sgr A*) that attracts the S2 star.

<u>Determining the revolution period, T, of the S2 star</u>

- With the help of the previous Excel graph, find out the <u>period</u> **T** of the orbit, in years then in seconds.

<u>Using Kepler's third law: mass M of SgrA*</u>

- from Kepler's third law: $\mathbf{T^2 / a^3 = 4.\pi^2 / G.M}$
- comes: $\mathbf{M = 4.\pi^2 . a^3 / G.T^2}$

For now, we will admit that the plane of **S2**'s orbit is perpendicular to the observation axis.

- With all this information, determine **M** (mass of Sgr A*).
- Compare **M** with the mass of the Sun (MSun = 2. 10^{30} kg).

PHASE 4: DISCUSSION

Explanation based on evidence / Consider other explanations

Ask students to read the following text below: the scientific article where the probable mass of Sag A* was first announced.

A. Eckart and R. Genzel

Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstraße, D-8046, Garching bei München, Germany

Accepted 1996 September 9. Received 1996 September 6; in original form 1996 August 6

ABSTRACT

We report the first results of a programme to measure proper motions of stars in the innermost core of the Galaxy. From high-resolution near-infrared imaging over the last four years we have determined proper motions for 39 stars between 0.03 and 0.3 pc from the compact radio source Sgr A*. For 19 of these the derived motions are more significant than 4σ in at least one coordinate. Proper motion and radial velocity dispersions are in very good agreement, indicating that the stellar velocity field on average is close to isotropic. Taking radial and proper motion data together the dynamic evidence is now strong that there is a $2.45(\pm 0.4) \times 10^6$-$M_\odot$ central dark mass located within ≤ 0.015 pc of Sgr A*. Its mass density is at least $6.5 \times 10^9 \, M_\odot \, pc^{-3}$, excluding the fact that the central mass concentration is in form of a compact white dwarf or neutron star cluster. In addition, we have detected significant changes in the structure of the innermost complex of stars in the immediate vicinity of Sgr A*, implying in at least one case stellar motions of ≥ 1500 km s^{-1} within ~ 0.01 pc of the compact radio source. Including this preliminary evidence, the inferred density of the central dark mass would then have to be in excess of $10^{12} \, M_\odot \, pc^{-3}$, implying that the central mass concentration is probably a single massive black hole.

Key words: astrometry – stars: fundamental parameters – stars: imaging – Galaxy: centre – infrared: general.

Figure 200 Abstract of Eckart and Genzel Paper

Data: $M_o = M_{Sun}$
pc = parsec= 3.26 light-years

- What is the real mass of SgrA*?
- Compare it to the one found by those researchers.
- If the plane of S2's orbit is not perpendicular to the observation axis, is the real mass of Sgr A* bigger or smaller than the one previously determined?
- Do you think that knowing the angle of the orbit is absolutely necessary to find out the nature of Sgr A*?
- Why is the name of this object Sgr A*?

PHASE 5: REFLECTION

COMMUNICATE EXPLANATION

Make an overview of what has been discussed in the classroom during the exercise. You may focus on the following issues:

a) Did you face any difficulties when analysing the data? How did you deal with them?

b) How does your analysis differ from the way astronomers analyse their data?

Ask your students to produce a report with its findings, presents and justifies its proposed explanations to other groups and the teacher.

PARTICIPATING ROLES:

In this scenario students are introduced to astronomical real data (images) and tools (software) so they can perform scientific predictions, analyse the observations, compare results and develop experimental models.

The teacher introduces students to the relevant concepts on the subject, asks important questions and identifies misconceptions, directs them to the scientific method, discusses the results with them.

TOOLS, SERVICES AND RESOURCES:

The scenario requires the use of:

1. Computers with internet connection;
2. SalsaJ software package installed (http://www.euhou.net);
3. Excel.

Appendix XI Methods and Data

This appendix presents the origin of the data presented in this thesis. Each set of data identifies the project, the chapter in the document where it appears, the procedure used, who obtained and what as the purpose.

Project: Digital Schools of Europe

Chapter: Appendix I - Digital Schools Self-Reflection Questionnaire

Procedure to obtain the data: Data was obtained using a modified google form. The modification was implemented using an existing plugin that enabled participants to save the responses already provided and continue at a later stage. It also enabled the user to see the results for each part of the survey. GDPR was ensured and users were informed about the procedure to have access to their data and to request the complete deletion of it. The survey was made available in the page of the project in Portugal (https://escolas-digitais.org/autoavaliacao/). An email was sent to all the school clusters in Portugal inviting them to take the questionnaire.

Who obtained the data: The data was obtained by NUCLIO

Purpose of the data: The main purpose was to verify the level of the Portuguese schools in the various dimensions of the self-evaluation tool. The survey is not finalized yet. The results have not been published yet with the exception of this dissertation.

Project: Discover the Cosmos

Chapter: 4.4

Procedure to obtain the data: The data collection and analysis was carried out with the online survey tool LimeSurvey and hosted at the BMUKK server Virtuellle Schule

Who obtained the data: The data was obtained by BMUKK with the support of all National Coordinators. NUCLIO was in charge of the collection of the data in Portugal.

Purpose of the data: The main objective was to identify the impact of the project tools, resources and overall methodology. The results were published in the deliverable presenting the validation results of the project to the European Commission.

Project: Inspiring Science Education

Chapter: 4.6

Procedure to obtain the data: The data collection presented in the chapter was automatically collected from the system analytics.

Who obtained the data: The data was obtained by IASA (Institute of Accelerating Systems and Applications), one of the partners of the project.

Purpose of the data: The purpose of the data was to evaluate the impact the project had in the use of the proposed material and impact on the students.

Project: Black Holes in My School

Chapter: Appendix III - Black Holes in my School Study (Pre and Post Questionnaire)

Procedure to obtain the data: The questionnaire was created using a google form. The pre-questionnaires were given to the students by the teachers prior to the engagement of the students in the exercise. The post-questionnaire was given at the end of the session or by the teachers after the students participated in the experience.

Who obtained the data: The data was obtained by NUCLIO

Purpose of the data: The main objective was to perceive if the exercise had the expected impact on the students participating in the project. More students will still be involved in the project and more data will still be retrieved. No publication was done yet with this data.

Project: Go-Lab Teacher's Community Support Framework

Chapter: Appendix IV - Teacher's Community Support Framework

Procedure to obtain the data: The questionnaire was created using a google form. The questionnaire was sent to the teachers that participated in the community building events, in particular summer schools and training events.

Who obtained the data: The data was obtained by NUCLIO and Ellinogermaniki Agogi (partners in the work package devoted to community building)

Purpose of the data: The aim of this survey was to understand the impact of the support strategy designed by the project. The results were published in a deliverable presented to the European Commission (Mavromanolakis, Doran, 2016).

Project: Go-Lab

Chapter: Appendix V - Teacher's Online Surveys

Procedure to obtain the data: The questionnaire was created using a google form and produced in a partnership with NUCLIO, Ellinogermaniki Agogi and Leicester University. The questionnaire was used during training events and engagement activities conducted by the national coordinators involved in the project.

Who obtained the data: The data was obtained by NUCLIO and Ellinogermaniki Agogi

Purpose of the data: The aim of this survey was to understand how the teachers were using the system, their perception on its usability and to support the participatory design actions. The results were published in a deliverable presented to the European Commission (Mavromanolakis, Doran, 2016).

Project: Go-Lab

Chapter: Appendix VI - Pre and Post Questionnaire Applied to the University of Coimbra's Students

Procedure to obtain the data: The questionnaire was created using a google form and produced in a partnership with NUCLIO and University of Coimbra. The questionnaire was presented to the students before their involvement in the use of Go-Lab (pre-questionnaires) and after the presentation of their assignments (post-questionnaires).

Who obtained the data: The data was obtained by NUCLIO and University of Coimbra

Purpose of the data: The aim of this survey was to understand the impact of the projects in bachelor and master students attending the Science Education course. The results are not yet published as more data was gathered and still in the phase of analysis.

Project: Go-Lab

Chapter: 6.4.1

Procedure to obtain the data: The data presented was retrieved from the Google Analytics and the Graasp Analytics

Who obtained the data: Google Analytics and EPFL

Purpose of the data: The data retrieved by NUCLIO and Ellinogermaniki Agogi was intended to analyse the impact of the engagement and training activities on the adoption of the Go-Lab ecosystem and to the materialization of classroom implementation runs. The data was presented in the project deliverables related to community building.

Project: GO-GA

Chapter: 6.10

Procedure to obtain the data: The questionnaire was created using a google form and produced by NUCLIO with the support of the partners in Africa (CcHub, Etrilabs and eLimu).

Who obtained the data: The data was obtained by NUCLIO with the support of the national coordinators in Africa.

Purpose of the data: The questionnaire was presented to the teachers participating in the bootcamps in order to retrieve their view on their participation on the project and their vision for future implementation. The result of this survey was presented in a deliverable to the European Commission

---

Project: PLATON

Chapter: Appendix VIII – PLATON Survey

Procedure to obtain the data: The questionnaire was created using Moodle modules. It was sent to all the teachers that participated in the pilot phase of the project.

Who obtained the data: The data was obtained by NUCLIO

Purpose of the data: The aim of this survey was to understand the impact of the project and the perception of the teacher's related to its importance and relevance. The data is not published yet. There is a paper in preparation.

Appendix XII Author's contribution to the various projects presented in this thesis

For the sake of completeness, the information in this appendix describes my contribution to the various projects and the research presented in the thesis. To my knowledge, none of the work presented in this thesis has been previously submitted in order to obtain a degree in this or any other university. The work presented in peer reviewed publications (in which I am co-author) or which was part of reports and project deliverables, was referenced within the text where it appeared. The work developed for Black Holes in my School was specifically produced for this PhD.

DSOE – Digital Schools of Europe

- Co-author of the proposal
- Project coordinator for Portugal in charge of the whole localization and implementation of the project in the country.
- In charge of the design of the dissemination strategy and reporting of dissemination actions for the whole consortium.
- Helped revise and update the roadmap and the self-reflection tool
- The data presented is new and has not been presented anywhere else. After completion of the data collection a paper will be prepared

Martians of Brandoa / Hunting for Open Star Cluster

- Support to the teachers during the implementation process. Support to the students for the development of the whole project.

IASC – International Astronomical Search Collaboration

- Support to the teachers during the implementation and training of the teachers conducting the campaigns

Global Hands-on Universe

- Co-founder of the Global Hands-on Universe Association
- President of the Executive Council
- In charge of the design of the implementation strategy of the project
- Internationalization of the project via its integration with the Galileo Teacher Training Program

European Hands-on Universe

- Project coordinator in Portugal
- Trainer for teachers in Portugal
- Developer of activities for the project, in particular the adaptation of Sun4all to the use of the digital tool Salsa J
- Organization of workshops for schools
- Support for the implementation in schools

Galileo Teacher Training Program

- Co-chair of the program during the first phase and Chair from the second phase until now (2019)

- Supported the recruitment of national coordinators at a global level
- Trainer of teachers and ambassadors participating in the project
- Responsible for the integration of the GHOU framework for teachers in GTTP

Discover the Cosmos

- Project coordinator for Portugal
- Developer of IBL activities
- Teacher trainer for the integration of the project in classroom
- Organizer and implementor of master classes in all participating schools.
- The data presented in this chapter has been presented in a deliverable of the project and the reference is in the text.

Open Discovery Space

- Project Coordinator for Portugal
- Trainer for teacher on the adoption of the ODS framework
- In charge of the community building efforts in Portugal
- Support to the school's self-evaluation process

Dark Skies Rangers

- Co-creator of the project structure
- Developer of the certification scheme
- Trainer for teachers participating in the project
- Organizer of sessions for schools
- Piloting of the initial framework for community building
- The cases presented in the chapter were publicly presented by the teachers supporting the research. To my knowledge there are no papers published.

Inspiring Science Education

- Project coordinator for Portugal
- Developer of IBL activities
- Teacher Trainer in Portugal
- Organization of sessions for schools
- Implementation of the research studies in Portugal and several other countries
- Co-Designer of the teacher training strategy devoted to improving the digital competence profile of the teachers
- Data presented in this chapter was published in a project deliverable

Black Holes in my School

- Development of the BHIMS exercise with support from Fraser Lewis who provided the images and prepared part of the technical annexes, in particular the "observing stellar mass black holes". The photometry annex was adapted from the original from the Faulkes Telescope Educational Team.
- Developer of the online course
- Trainer of teachers in the face-to-face sessions
- Adaptation of the exercise to online platforms (i.e. Go-Lab and ISE)
- Implementer in Portugal and other countries
- Co-author to the theoretical information about black holes retrieved from the Portal do Astrónomo
- The support to the students was also provided in a partnership with Fraser Lewis
- Development of the evaluation tool
- The black hole lurked at the centre of our Galaxy is originally from the European Hands-on Universe in France

- All the data retrieved in the framework of this project is original and has not been published yet.

Go-Lab

- Project coordination Portugal
- Development of ILSs
- Training of teachers in various countries
- Support to school's implementation
- Responsible (for the second half of the project) for the community building work-package
- Development of the 5 pillars of community building
- Development of the competence profile for a Go-Lab teachers
- Co-development of the community support evaluation tool
- The 5 pillars of community building and the competence profile of a Go-Lab teacher have been present in a paper that is submitted but not published yet, as referenced in the document. It was also presented in a project deliverable as reported.
- The data related to the evaluation was presented in a project deliverable
- The results of the analysis presented in this chapter have been submitted in a project deliverable, as reported in the document.

NEXT-LAB

- Project coordination Portugal
- Development of ILSs
- Training of teachers in various countries
- Support to school's implementation
- Support to the integration of the Go-Lab concept to University Students
- Co-organizer of the summer schools
- Support to the development of the evaluation tool for the Coimbra's University Students
- Creation of the tutorial on how to organize a teacher training session
- The data presented in the document related to the Coimbra's student's evaluation was not published yet.

GO-GA

- Coordination of the Master Teachers and Large Scale Onboarding of Teachers Work-Package
- Co-Designer of the Bootcamp courses
- Trainer during the bootcamps
- The data retrieved from the project was presented in a paper as reported in the document

PLATON

- Project coordinator
- Co-creator of the WIIL methodology
- Trainer of teachers in various countries
- Development of IBL activities
- The data presented in the document has not been published yet. There is a paper in preparation.