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Diffusion of Online Labs and Inquiry-Based Science Teaching Methods and Practices Across Europe

Georgios Mavromanolakis, Sofoklis Sotiriou

Research and Development Department, Ellinogermaniki Agogi, Pallini, Greece

Email address
gmavroma@ea.gr (G. Mavromanolakis)

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Abstract: This paper addresses the challenge of modernizing science teaching in secondary education schools by introducing and implementing the use of online labs and inquiry learning approaches and by proposing and offering an integrated framework of methods and tools that are freely available to science teachers and educators. An advanced educational repository (Global Online Science Labs for Inquiry Learning at School - Go-Lab) was developed to offer access to a unique collection of online labs and relevant resources for this purpose. In this paper we first describe and discuss the objectives and the methodology for diffusion of online labs and of inquiry-based science teaching methods and practices across the participating European countries. Then the quantitative results and qualitative outcomes of the methods adopted are also presented and discussed in detail. The data are coming from 1000 schools with the participation of several thousand teachers and students in 15 countries across Europe and beyond. These school communities have used the Go-Lab repository for three years. The collected data and their analysis indicate that a) teachers – having access to numerous resources – are progressively adopting existing resources and finally developing their own lessons based on the inquiry approach and b) that experimentation with online labs could be effectively integrated to the existing school curricula.

Keywords: Inquiry-Based Science Education, Large-Scale Implementation in Schools, Best Practices, Communities of Practice, Online Science Labs, Inquiry Learning

1. Introduction

Europe needs its youth to be skilful in and enthusiastic for science and regard it as potential future career field to guarantee innovation, competitiveness and prosperity. To ensure this, large scale initiatives are needed that engage students in interesting and motivating science experiences [1, 2]. To achieve this, the Go-Lab project's approach is to offer to teachers and their students a well organised federation of remote laboratories, virtual experiments, and data-sets (all together referred to as "online labs") along with supporting, easy to access, lightweight end-user interfaces and frameworks that facilitate the use and adoption of them in the classroom practice and create an out of the ordinary engaging educational experience [3, 4, 5, 6]. Furthermore, teachers are supported and guided to develop, implement and share their educational scenarios and build a wider community of practitioners that promotes the best practices across Europe and beyond. The main objective of the Go-Lab initiative was to implement this approach at large scale in Europe, namely at 1000 schools, in 3 pilot phases, in the 15 participating countries of the consortium (the Netherlands, Greece, Bulgaria, Romania, Belgium, Poland, Italy, Cyprus, Germany, Spain, Austria, Estonia, Switzerland, UK, and Portugal).

2. Methodology

Of particular concern in our approach was how schools and science teachers can be approached initially and then be further engaged in implementing Go-Lab activities in their classrooms [7, 8, 9, 10, 11]. A well-designed, detailed, clear and systematic work plan and implementation scheme and strategy was laid to achieve this at large-scale and realize an effective and successful diffusion of inquiry-based science teaching methods and practices across schools in Europe. Two complementary main methods of approach were devised, a. top-down method of approach and b. bottom-up method of approach. The deployed methods of approach had already proven their efficacy before [12, 13, 14]. And in the case of this project they were also proved successful, as can be seen by the quantitative and qualitative results reached that are discussed in the next sections.

2.1. Community-Building: Developing a User-Centered Support Mechanism to Involve Teachers

In this approach the Go-Lab team used official channels of communication to approach and invite teachers/schools to project activities such as introductory seminars, training workshops etc. In each country a National Coordinator or local partner was in charge to contact the district's school counsellor or regional bureau of education or other equivalent authority and to inform them about the project. An introductory-informational event was initially arranged and teachers from the area are invited officially to attend. Teachers who were interested further in applying Go-Lab in their science classroom are given further guidance and support material with educational content (i.e. classroom scenarios using online labs) to start with. If needed additional events to provide training and practicing were organised.

2.2. Bottom-up Method of Approach

Partners organize informational events and visionary workshops inviting science teachers from schools in their local area. In addition, several consortium partners had previous experience and collaborated within the framework of European projects on education with pioneering and innovative science teachers. In this case partners approach directly these already known teachers, and possibly through them their network of colleagues, informing them about the project. Also, within this approach the National Coordinator or partner in each country contacts science teacher societies and national professional unions, participates in their conferences or annual meetings by giving a talk or seminar or arranging workshops to be held during these events to inform and attract teachers. Partners that are being or operating within institutions of higher education can approach faculty members in the Dept. of Education in their own or local university who are involved in research on science education. Through them can be approached teachers and schools with whom they are currently conducting field research or have collaborated in the past.

3. Implementation and Diffusion of Activities in Schools Across Europe

The implementation of the Go-Lab project took place in 3 phases, A, B and C, covering 3 consecutive school years. The pilot schools were mainly recruited from countries where partners are based (the Netherlands, Greece, Belgium, Cyprus, Germany, Spain, Austria, Estonia, Switzerland, UK, and Portugal) and additionally from Bulgaria, Romania, Poland and Italy. In Phase-A more than 100 pilot schools were recruited. In Phase-B about 500 more schools were added in the network of pilot sites. In Phase-C 500 more schools from the network of countries joined the activities of the project. Phase-A lasted 6 months, Phase-B and lasted 9 months and Phase-C also lasted 9 months. Before and during each phase various in-school implementation and community building activities were planned to take place in each country organised by the partners of the consortium to attract, engage and train science teachers in the Go-Lab project so that they then implement its approach in their schools.

In general, an implementation activity intends to bring into the classroom practice the use of online labs and related resources in an innovative and engaging way so that both teachers and students have a stimulating experience in science education. Series of support activities for teachers, such as presentation seminars and training workshops, are organised for them to get familiarized with the relevant technology, gain knowledge and confidence and be able to adopt, and adapt, the use of online labs in their everyday school practice.

These activities were managed locally by one partner in each of the pilot countries who acts as the National Coordinator and is responsible for the local management and localization of the project resources and activities. For Phase-A and B national coordinators and partners offered and conducted comprehensive training for teachers covering the pedagogical and technical aspects of the Go-Lab approach. They also organized and conducted several activities where students participated. They continued the effort during the third and final phase keeping a good balance between teacher trainings and in-school activities with students. For each partner activity a report according to a template was issued. The implementation activity reports compose a key part of the management and coordination of the overall effort, and as well of the public image of the project. Material included in them were usually used also in dissemination actions and project promotion documents.

In the following, first are presented the summative results of implementation activities conducted by partners during the project. Then follows the analysis of the data from the usage of the system.

4. Results

The implementation phases covered the period of three years. During that period partners organized series of implementation activities, training workshops for teachers and activities with students in schools around the host countries and beyond. The total summative results after Phase A, B and C are: 1692 teachers from 1041 schools attended the training workshops that partners organized (Figure 1); 4283 students from 218 schools participated in the activities that partners organized (Figure 2).

4.1. Teacher Trainings

We experienced a large variation on the number of teachers that participated in trainings organised per partner country in Phase A, in Phase B, in Phase C and in total. This is expected and explained to some extent after considering the difference in allocated person-months and resources per partner to conduct activities with schools, teachers and students. Further to that the variation of achieved results is because of several systemic factors, among others: the flexibility of the national educational system in introducing innovative methods and practices in science or Science-Technology-Engineering-Mathematics (STEM) education or in general; the current computer and network (ICT) infrastructure in schools. This refers to the status of baseline software and hardware equipment, frequency of regular upgrades, ratio of availability per student or classroom etc; the general attitudes, skills and interests of teachers. This includes the level of motivation and encouragement they need to exit from their comfort zones.

Throughout the implementation phases of the project it is observed that the most crucial factor is being the culture and attitude of science teachers, and in general the education system across different countries and how flexible or prone they are in adopting inquiry teaching and innovative learning approaches, the use of online labs in science education etc. The second most significant factor is being the flexibility of the national curriculum and the level of freedom is allocated to schools and teachers to choose, design and implement their teaching practice. In this context in Greece, Spain, Portugal, Cyprus, Estonia, better overall results were achieved compared to other countries like in Austria, Germany, UK and Switzerland.

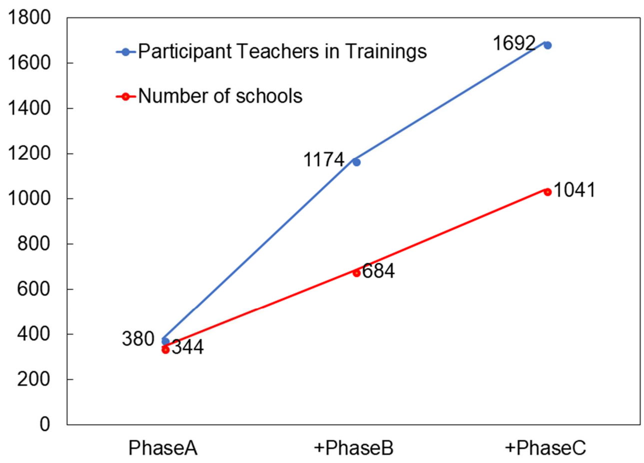


Figure 1. *Cumulative numbers of participation in teacher training activities organized in Phase A, B and C.*

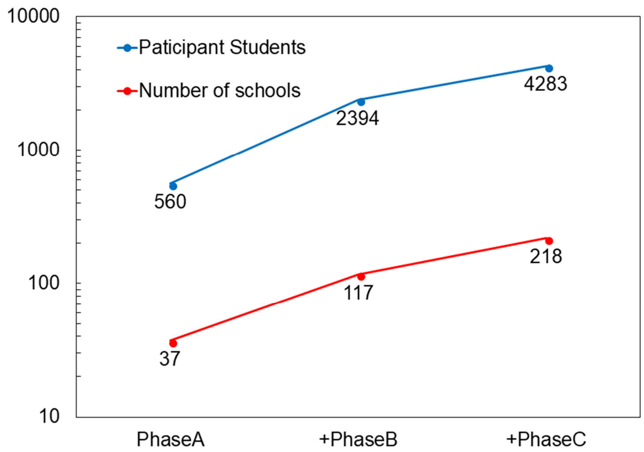


Figure 2. *Cumulative numbers of participation in student activities organized in Phase A, B and C. Note that the vertical axis is in logarithmic scale.*

4.2. Educational Activities for School Students

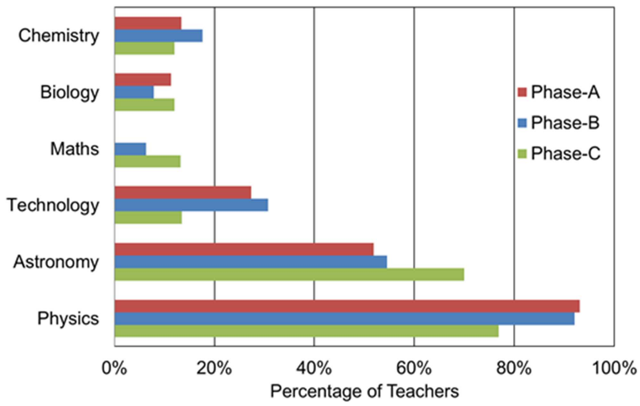
During the implementation of the project it is generally observed that in most countries and cases there was large expression of interest from schools and teachers to join the project and attend the trainings. However, teachers then found considerable difficulty to implement what they learned in their everyday teaching practice. As a result, the national coordinators and partners devoted significant effort to organize and conduct themselves in-school activities with students to demonstrate and facilitate their uptake, and to provide support to teachers.

As already mentioned there is large variation on country per country level due to these factors. Further to these, the expertise and the experience of partners responsible in conducting such activities in secondary or primary education played a critical role. In this context in Greece, Portugal, Cyprus, Estonia, better overall results were achieved compared to other countries. These are also in line with generally a better achieved balance between teacher trainings, follow-up student activities and overall distribution of schools involved.

4.3. Subject Domain of Online Labs

The online labs that partners demonstrated and introduced to schools, teachers and students during the activities of implementation were from three categories: 1. simulations and virtual labs, 2. datasets and 3. remote physical labs. The activities with teachers and students that practiced and utilized these online labs were linked to various science curriculum domains, in particular: to Physics, Astronomy, Technology/Informatics/Electronics, Chemistry, Biology and Maths. Their classification in terms of subject domain is shown in Figure 3 for teacher trainings and activities with students, respectively. In summary, for teacher trainings the grand majority is on Physics with 77% and Astronomy with 70%, followed by Technology-Informatics-Electronics 13%, Maths 13%, Biology 12% and Chemistry 12%. For student activities the corresponding subject domains are: Physics 73%, Astronomy 23%, Maths 15%, and Technology, Biology, Chemistry of about 1% each or less.

The achieved distribution of subject domains is mainly due to the expertise and the experience of the partners involved and, to some extent, because of the schools' and teachers' preferences and demands. It also reflects the core subjects of the science curriculum wherein most commonly teachers find opportunities to utilize online labs in their teaching or to link with interdisciplinary educational activities.



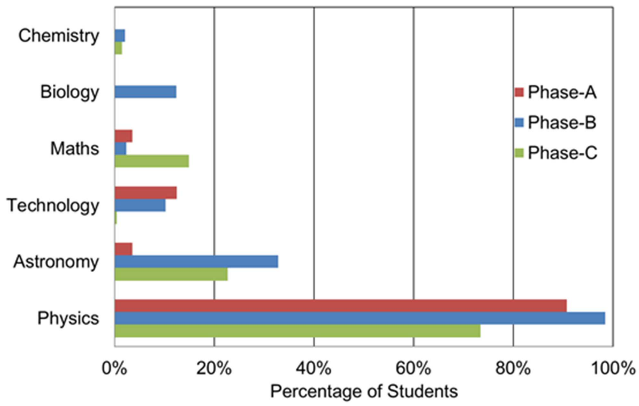


Figure 3. *Subject domains of online labs demonstrated and practiced in teacher trainings (top) and utilized in student activities (bottom) organized by partners in Phase A, B and C.*

4.4. Analysis of System Data

During the last year of implementation, we had a smooth continuation of the in-school activities of the project with stable and mature system and with plethora of high quality inquiry activities available in public, shared or private online lesson plans (called in project terminology Inquiry Learning Spaces or in short ILS) developed with the authoring environment of the project. During the last year and phase of the project larger number of teachers were authoring and producing complete and better ILSs and using them with their students. At the time of writing there are almost 450 ILSs which are published in the golabz.eu repository, with more than 85% of them made by teachers, in various languages and subjects. In addition, there are more than 1000 ILSs which are in constant use but unpublished.

The analysis of the system usage data shows a direct indication of the constant and wide uptake of Go-Lab and the impact of the implementation activities and the related effort that was devoted by the consortium partners as discussed in the previous section. In the following we present the results from the analysis of the system data.

4.4.1. Time Evolution of Use

The system log data and their thorough analysis offer us an independent and objective way to study the actual usage of the system, its main characteristics, how and when ILSs are created and implemented, how the overall population of users evolve in time etc. In this context, from Oct 2014 and since the migration to a new and improved system (online repository and authoring environment) until the end of Phase-C (Jul 2016) 6517 new users registered and created an account in the authoring environment. Of whom 3877 became creators and authors of 1470 ILSs as counted with minimum quality criteria (e.g. ILSs with all inquiry phases according to the proposed Go-Lab inquiry cycle, with at least five standalone student views, etc.). These figures show a more than 100% increase when counted from the start of Phase-C (Oct 2016) as can be seen in Figure 4. When compared to the total number of teachers participated in the partner trainings we see that we reached a multiplication factor of 3.85 with respect to number of registered users per trainee, and 2.29 with respect to content authors per trainee. This reflects the fact that more experienced and advanced teachers were training and tutoring their less experienced colleagues, which is in line with what national coordinators and partners had observed during their interactions with participants at the training workshops.

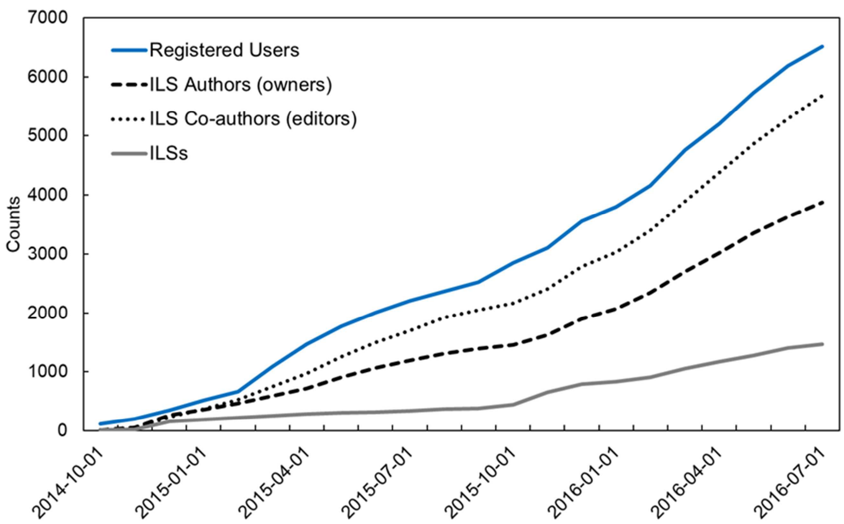


Figure 4. *Time evolution of registered users, authors and editors, and ILSs created in the authoring environment.*

Figure 5 shows more qualitative parameters and how they evolved through time for the last two implementation phases. We observed that the number of registered users that correspond to an author of inquiry content quickly improved since the start of trainings from Phase-B, Oct 2014, and stabilized to an average value of 1.68. This means that on average about 2 out of 3 users they actively used the authoring environment and the offered tools to adapt or create their own ILSs. In the same figure, the curve of authors per ILS shows a more seasonal behavior which coincides with the periods that schools and teachers are in duty. It had a variation between about 2 and 4, with an overall average value of 2.64. This reflects the fact that teachers were gradually and sharing content with two or more other users or/and worked collaboratively with colleagues in the design and development of their ILSs.

In addition to above, a more significant qualitative change in the behavior of users and how the system was utilized in practice is shown with the curve "standalone viewers per author". The term standalone viewer refers technically to the action of viewing an ILS by students that access it with nicknames or passwords given by their teacher. As can be seen there was a clear and distinctive rise after summer 2015 and since the start of the corresponding school year that spanned the last implementation Phase-C. This constant increase shows clearly that progressively more and more teachers are utilizing their ILSs with their students. At the end of the phase it reached the value of 9.4. Considering that on average a typical school classroom consists of 20 to 25 students this means that on average about 2 students are sharing a PC to login and access the ILS taught. This is consistent with observations from national coordinators and partners and in particular from those who organized and implemented themselves activities with students in school classroom settings. The summative reported numbers (see Figure 2) for the activities that conducted by partners are 4283 students from 218 schools, which corresponds to 19.6 students per classroom.

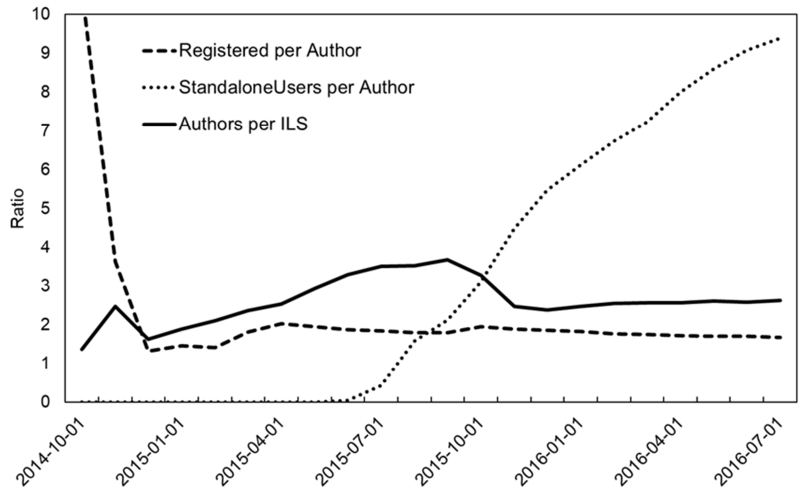


Figure 5. *Time evolution of the number of registered users per author, standalone viewers and authors per ILS.*

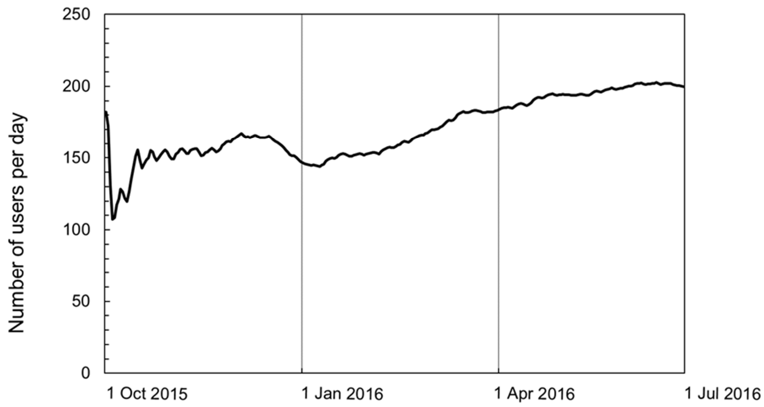


Figure 6. *Number of users per day in the authoring environment during the last implementation phase of the project.*

The above mentioned quantitative and qualitative change in the behaviour of users and the overall achieved usage of the system is a combination of several factors, among others: 1. maturity and proficiency of users; 2. consequent creation of a significant critical mass of teachers who produced in abundance a large variety of high quality ILSs in various languages, subjects and complexity levels; 3. abundance and variety of online labs and supportive apps in the portal; 4. technical improvements that made the system and the authoring environment more user-friendly.

The final effect is apparent in Figure 6 that shows the number of users that access and work in the authoring environment daily. At the end of Phase-C 200 users per day are utilizing the services and tools of the system to design and create inquiry lessons with online labs, to share or co-author content and to deliver it to school classrooms throughout Europe and beyond.

4.4.2. Usage of Online Inquiry Learning Spaces

The system log data gives us also the opportunity to analyze and estimate the overall usage of ILSs, time duration, repetition rate etc. The analysis was based on 768 ILSs that passed a set of strict quality criteria (e.g. threshold value of standalone viewers of more than 10, usage of all phases of inquiry, minimum time of ILS usage of at least 15 mins, etc.) that were applied to the raw database.

The distribution of the selected ILSs as a function of how many times they were used (in settings of at least 10 standalone viewers, which correspond to 10 connected PCs or equivalently to at least 20 students) is shown in Figure 7. We observe that the ILSs are implemented with on average about 50% of cases are a single time, about 30% are 2-3 times, about 11% are 4-6 times, about 8% are more than 7 times. On average this corresponds to an average repetition rate of 2.8 times that an ILS is implemented. In total these ILSs were implemented with 21420 standalone viewers which roughly correspond to more than 40000 actual students. It should be noted that these estimates are on the conservative side if we take into consideration the fact that in many instances school classrooms were equipped with less PCs or equivalently had a higher ratio of students per connected PC.

The results of the analysis of data with respect to duration of usage of an ILS is shown in Figure 8 below. As can be seen from the upper curve overall in about 60% of the cases the duration of usage of an ILS is for about 43 mins. The long tail is understood due to cases where an ILS is partially implemented during classroom hours and then its usage was continued by students as homework, or for added assignments or in extra-curriculum activities. If one considers only in-school hours, typically from 8:00 until 15:00, then about 44% of the cases fall in this category as shown in the lower curve of the graph. This is well consistent with data from surveys of teachers about how they utilized and implemented in their classrooms the offered services. It should be also noted that both curves are reproduced by power law distribution functions. This is typically expected to describe a dynamic system of large size of e.g. physical, biological or social nature.

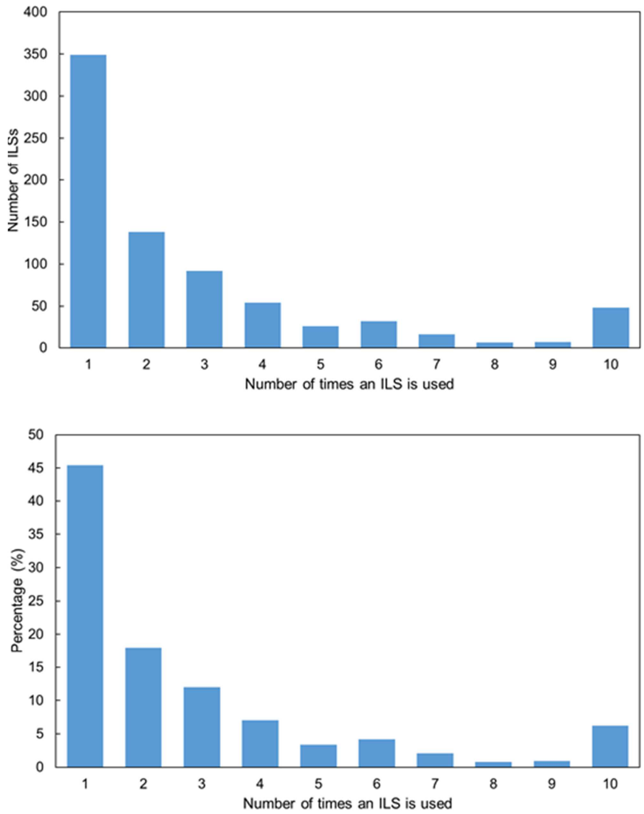


Figure 7. (Top) Number of ILSs versus how many times were used in classroom settings of at least 10 PCs which correspond to about 20 actual students. (Bottom) Percentage of ILSs versus how many times were used. (Note: last bin refers to values more than 10)

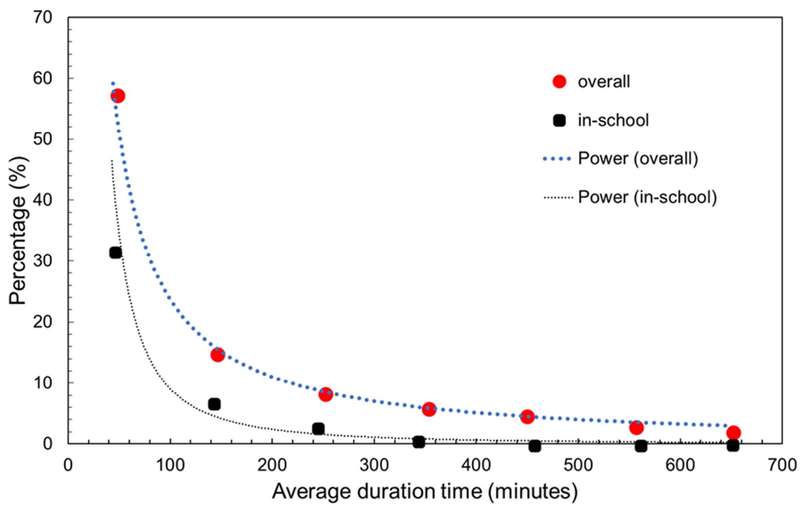


Figure 8. Distribution of average duration time an ILS is implemented. Dashed lines are power-law fit to data and are added to guide the eye.

5. Discussion

In summary, throughout the implementation phases of the project national coordinators and partners organized and conducted series of implementation activities with teachers and students reaching a large audience across countries. Following an overall implementation plan and inclusive strategy they engaged schools, teachers and students in the use of online labs and inquiry-based approaches of science teaching and learning. A constant and wide uptake was realized laying the foundations for successful sustainability and broader impact that continues well after the official end of the project. Below are listed the main key quantitative and qualitative indicators achieved.

1. 1692 teachers from 1041 schools attended the training workshops that partners organized;
2. 4283 students from 218 schools participated in the activities that partners organized;
3. 6517 new users registered in two years and since the beginning (Oct 2014) of employing the systematic approach as described in this article;
4. 3877 became creators and authors of more than 1470 ILSs;
5. 200 users per day are utilizing the services and tools of the system;
6. More than 768 ILSs of high quality criteria implemented in schools (44% of cases during in-school hours), with an average repetition rate of 2.8 times, reaching more than 40000 students.

These data indicate that: a. we have achieved multiplication factors of 3.85 with respect to number of registered users per trainee, 2.29 with respect to content authors per trainee; b. 2 out of 3 users they actively used the authoring environment and the offered tools to adapt or create their own ILSs; c. Users sharing content with on average 2.64 other users or/and worked collaboratively with colleagues in the design and development of their ILSs.

Furthermore, they show that, on one hand, teachers – having access to numerous resources – are progressively adopting existing resources and finally developing their own lessons based on the inquiry approach, and, on the other, that experimentation with online labs could be effectively integrated to the existing school curricula. It is clear though that an effective support mechanism must be in place for the realization of such a large-scale intervention.

6. Conclusions

Teachers as content developers

Monitoring the perception of the participating teachers showed a clear turn towards the use of proposed digital resources (online labs, apps and inquiry learning spaces) in their classrooms. When initially involved into the project, teacher first were mere users (by exploiting the offered services), before they finally developed inquiry learning spaces by their own beyond mere lesson plans acting as contributors to the Go-Lab platform sharing with others. Altogether, 66% of our participants showed this turn as within a three-year time frame 3877 became creators and authors of more than 1470 ILSs. It is very important to have a clear overview of the experiences and the skills of science teachers as well as a good knowledge of the environments where teachers operate. A close look at teachers teaching and technical skills reveals that a large percentage of the teachers that are interested in the use of on-line labs have quite developed pedagogical and technological skills. Thanks to the diversity of options that the Go-Lab tools offer, teachers with less experience have the possibility to start discovering the tools by using the repository and identifying labs, apps and existing ILSs that fit their needs. This is a crucial parameter for such interventions.

Diffusion of inquiry methods in school classrooms

In the framework of the Go-Lab project the pedagogical model used was based on inquiry approach. One can consider that the focus of inquiry results in more complex and demanding interventions but according to our view the integration of on-line labs in school curricula must be based on a strong pedagogical framework. In any case inquiry is currently in the agenda of the most educational reform efforts in Europe. Most of the Go-Lab teachers have some knowledge of inquiry. Most teachers seem confident in teaching inquiry to their students and to design related activities. Still a significant number of teachers do not feel confident using inquiry. Some consider that they still lack skills to successfully apply it. For others, the problem remains to be the curricula restrictions that do not offer space for such interventions. Continuous support, good practices and training are needed in order support teachers interested in inquiry and help them fully develop their inquiry skills. It must be noted that the focus on inquiry was a design decision of the Go-Lab considering that numerous reform efforts in European countries bringing inquiry as a top priority of their agendas. Could on-line labs lower the barrier that is the time constrains in the implementation of inquiry interventions in classrooms? According to our view, Go-Lab has managed to optimize the use of on-line labs as a way to introduce inquiry in school classrooms. Teachers seem to be quite confident to use on-line laboratories and repositories. The use of authoring tools though, is a big challenge for most teachers which also affects their intentions and ways they use the Go-Lab tools. At the end of the second phase of pilot work we can see a change in teachers' technical skills with a significant rise in the numbers of teachers who are developing their own educational materials. The various supportive materials that were made available during the previous year and the training sessions that took place all around Europe, have played their role and contributed to this change. It is important to note that both curriculum developers and providers of online labs should make sure that effective and continuous technical support must be provided to teachers. More specifically providers of online labs should follow modular and flexible support schemes to cover the different training needs of teachers.

Teachers as co-designers of the reform efforts

The use of Go-Lab helped teachers to gain familiarity with the basic principles of authoring tools that they can use in producing their own ILS. As a result, we can see a great shift regarding the use of Go-Lab. This is a very important outcome according to our view. Both curriculum developers and on-line labs providers could rely on teachers for the development of educational materials that will facilitate the integration of on-line labs to the curriculum. Teachers have the knowledge and the skills to adopt and design localized scenarios adapted to their classroom needs. The user-friendliness and the usability of the tools are crucial here. On-line labs providers should make sure that their services are accompanied with the necessary support infrastructure that will give teachers the opportunity to localize the proposed tools to their lessons. This approach holds a great potential. Teachers can become participants in the reform processes by designing innovative scenarios but at the same time introducing new scientific knowledge that is not available to the current curricula.

Need for reward mechanisms

Additional actions need to be taken it order to motivate teachers to fully participate in the validation process. Incentives, rewards, connection to certification are just some of the suggestions and possible solutions that must be considered. If teachers are becoming co-designers of the reform efforts specific recognition mechanisms have to be in place. Curriculum developers and providers of online labs must trust teachers' professionalism and to devote significant resources on teachers' professional development programmes. The main recommendation from our work is that teachers could be co-designers in the reform efforts. Instead of allocating resources to developing new educational materials curriculum developers have to offer to teachers the appropriate guidance and support to harmonize existing resources to their needs.

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