The role of technology in educational settings has become increasingly prominent in recent years. When utilized effectively, the ICT tools provide a higher quality of learning for students and a new stimuli for teachers.

The "Do Well Science" project, funded by the Erasmus+ Programme, KA2 - Strategic Partnership in the field of School education, covered ITC tools and STEM subjects aimed at increasing secondary students learning results in Maths, Physics and Natural Sciences through the development of a new software architecture and learning and teaching packages addressed to both teachers and students.

This guide means to present the results of the project and it is mainly designed to be relevant for all learners of higher school worldwide and to find its application in all sorts of learning settings.

Educators can use this text as a resource when developing training on Science in formal and non formal educational settings. Policy-makers may find it helpful to consider core ideas when developing education policies or strategies. It can also be used to build on existing work in ESD and related areas such as global citizenship education, environmental education and others.

Because the target group is diverse and possible uses of this guidance are manifold, while in their concrete implementation they will, naturally, have to be adapted to the national or local context.

Massimo Amato

Massimo is graduated in Aerospace Engineering in 2001. After three years as Project Manager for an International Company he started working as teacher in Mathematics, Physics and Information Technologies in high schools. Over the years, he has played important roles within the schools and at the Lyceum "Machiavelli" is responsible for two school and safety management commissions, security and prevention. Always aware of the new technologies and the dynamics of teaching, he focuses on student engagement for dynamic, effective and long-term learning. He had participated in the Erasmus+ "Goerudio" project, is involved in other two European projects under the Erasmus Plus KA Strategic Partnership has been doing research in Maths teaching through music, he's in contact with North Caroline School of Mathematics and Science to interchange the experiences and methodologies of Science teaching. He is the coordinator of "Do Well Science" Erasmus Plus project.

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Manual for Innovative Pedagogy in STEM Contents

Liceo "Niccolò Machiavelli"

Florence, Italy

DO WELL SCIENCE

Manual for Innovative Pedagogy in STEM Contents

An Erasmus+ project to increase secondary students' achievements in Science subjects

Edited by

Massimo Amato and Anna Siri

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OVERVIEW ON SCIENCE TEACHING, RATIONALE, NEEDS AND CHALLENGES

1. Science, Technology, Engineering and Mathematics (STEM) Education in Europe

by Massimo Amato, Emanuela De Negri, Jan-Eric Mattsson, Ann Mutvei, Anna Siri

1.1. Introduction

Sciences taught are based on many different aspects such as the training received by the teachers, the content of the school programs and the standardized tests represent the main elements, which influence, directly or indirectly, the contents, the approaches and the scientific activities organized in the classes. The development of concepts is linked to mental images and models that are formed in the mind. Making a model of a concept means subsequently reworking weak and unstable images that,however, have to convey a definitive image, strong and stable. Lectures are indispensable but sometimes do not compensate for past gaps or difficulties "of the moment" that the teacher is not always able to satisfy for each individual student, given the high number of learners in the classroom.

"Do Well Science" is "for students with students". Its aim is to increase problem solving skills in students, to provide resolutive methods, to get ad hoc built exercises, to actualize the problems referred to in the classroom with videos, documents, and in general with the resources available on the web.

"Do Well Science" wants to develop a teaching methodology and wants to provide a large number of resources using the environments most familiar to students: websites and dedicated applets for Mathematics, Physics and Natural Sciences.

"Do Well Science" allows students to:

- easily identify the support, strengthen the verification activities to be carried out in the individual discipline;
- easily identify laboratory activities and experiments for the enhancement of the single discipline;
- identify the references to daily life and natural phenomena related to the topics discussed in the classroom for a fruitful study;
- search, highlight and investigate scientific issues of interest to them;
- work in groups and create moments of confrontation, relationship and positive discussion.

Existing websites, applets for tablets and smartphones in Science education are not very user friendly and are often incomplete, approximate or without a didactically verified structure.

"Do Well Science" wants to be a web platform and at the same time one applet that allows users, students and teachers, to make comments, suggestions and proposals for exercises and problems. Through the statistical analysis of the use of resources, it will be possible to delete those exercises that are not used and deepen the topics most requested by students. The platform will offer a good study practice, allowing the participation of the students, it will increase the skills by stimulating the will to do well. The e-learning shared among the students will be allowed also through the publication of the results obtained, through the achievement of objectives and the increase in level that allows the earning of better badges. A championship will be created that allows the participation into a healthy competition for a profitable and lasting learning.

The analysis and the study of the "Do Well Science" method requires a careful and detailed analysis through skilled personnel who has been following the issues related to learning for years: high school teachers, university professors, qualified staff of the school's public bodies.

1.2. Overview on the main European policies on STEM

Due to the attention of the European Community on the ever increasing awareness of the development of methodological and technological innovation in schools, the aims of this project are to develop a new software architecture designed for the construction of e-learning environments, Learning Management System - LMS and content management system, CMS with which it is possible to train, assess and eventually certify the competences of students, updating the request for a wide representation and dissemination of knowledge and innovation experiences, implemented within individual schools, by teachers and for students.

According to the OECD-PISA surveys, the training of students in Science subjects deteriorates progressively over the years [1]. The Council of the European Union has set the goal of reducing the percentage of 15-year-olds with poor results in reading, Maths and Science by 15% to 2020.

According to Eurydice [2] Science provides students with the tools to better understand the world around them, encourages curiosity and a critical spirit, emphasizes the relationship between man and nature and reminds us that natural resources are not unlimited.

The #EuFactor project [3] of the European Commission and the European Parliament sensitizes young people to the study of Science, technology and information technology, in view of the new job opportunities and the skills required by the market; for Europe, growing means innovating and innovating means growing. According to a study by the European community between 2013 and 2025 it is estimated that in Europe there will be around 2,300,000 vacancies in the field of Science and engineering.

In Italy, the INDIRE - National Institute for Educational Research Innovation Documentation [4] through its research activities, supports innovation in the Italian schools and addresses the processes of transformation of methodologies and educational tools, thus helping to spread new teaching and learning practices and models. Furthermore, with reference to the lines followed in the context of the National Digital School Plan – PNSD [5], which promotes the development of digital skills and supports students' learning activities in a stimulating and attractive manner, the "Do Well Science" project ensures the use of functional and effective resources made available by the PNSD.

Walter Lewin, former professor at Massachusetts Institute of Technology: "Children must love Science and the teacher must ensure that they succeed. Clarity is essential to achieve this goal."

1.3. The EU STEM Coalition

The EU STEM Coalition is a Europe-wide network of national STEM platforms [6] aiming at a close cooperation among governments, education and industries, and has strongly regionalised its implementation. STEM platforms are organisations, usually, established by governments to increase the number of STEM graduates and reduce skills mismatch.

The EU STEM Coalition is a Europe-wide network of national STEM platforms in the long term, the EU STEM Coalition aims at reducing the skills’ gap by having a national STEM strategy in place in all of the EU member states.

The EU STEM Coalition aims at:

- facilitating the exchange of best practices among national STEM platforms;
- supporting member states in the development of new STEM strategies based on the triple helix approach cited above.

The idea of the Triple Helix of academia-industry-government relationships was introduced in the 1990s. Its main hypothesis is that the potential for innovation and economic development in a Knowledge Society lays in the effective collaboration among academia, industry and government. Experience has shown that this approach is effective when following a national STEM strategy due to ensure that all stakeholders are involved and engaged, and that the implementation of national STEM strategies is sustainable and fully aligned with the national and regional context and goals.

The EU STEM Coalition consists of national STEM platforms, of European partner organisations (organisations that represent a relevant group of stakeholders) and of national lead partners (organisations that are mandated or in the process of establishing a national STEM platform). The EU STEM Coalition also closely cooperates with a variety of European, national and regional partners including national and regional governments, industry and EU level institutions including the European Commission and the European Institute for Innovation and Technology, EIT.

The ‘general meetings’ and ‘taskforce meetings’ are the main activities of the EU STEM Coalition. The general meetings include all members of the EU STEM Coalition and focus on a specific theme (e.g. industry-education cooperation, girls in STEM, …). The main outcomes of these meetings are thematic reports in which the approach and practices of each of the members is mapped. The "taskforce meetings" are also triggered when the EU STEM Coalition is approached by another EU member state for help with the development of their STEM strategy. Based on the outcomes of the preparatory discussions with the member state, in which the thematic reports are used to develop a strategy, a taskforce is assembled in alignment with the national objectives and preferences of the country. All meeting reports and materials are available through the publications page.

The institution of a Jet-Net programme for school-company collaboration in Denmark based on the Dutch Jet-Net programme and the establishment of an Estonian Technology Pact and the development of a Hungarian STEM platform are both successful examples of best practice sharing between members of the EU STEM Coalition that have led to concrete results.

Out of the participating countries in this project Bulgaria and Greece are represented in the EU STEM-Coalition, Bulgaria by The Ministry of Education and Science and Greece by FORTH, the Foundation for Research and Technology-Hellas [6].

1.4. Conclusion

"Do Well Science" is consistent with the horizontal priorities identified by the European Commission, in particular it:

- improves academic performance on the basis of the student's basic and transversal skills, with a view to lifelong learning;
- allows the development of learning abilities of scientific subjects even for learners who start from disadvantaged situations of language, relationship, social status, ... but who have the possibility of using information technology, possibly even just at school;
- helps to develop the skills of all students, reducing the disparity in learning outcomes in students from disadvantaged backgrounds, since it uses an innovative and integrated method in the teaching of the single community country;
- uses an open and innovative pedagogy, based on the digitization of contents, in which teachers and students are invited to interact for a general increase in the quality of education;
- allows educators to keep up to date with students' requests to reduce disparity and early school leaving, enhancing innovative pedagogies;
- allows to easily identify the gaps and to recognize and enhance the skills acquired.

"Do Well Science" is consistent with the specific priorities identified by the European Commission, in particular:

- in the context of higher education, it:
  - promotes the development of new ways of delivering learning, exploiting and adapting to new technologies for learning and teaching.
- in school education, it:
  - increases performance in basic Maths, Physics, Chemistry and Science skills;
  - uses an innovative approach focused on the student and on active learning;

- uses interdisciplinary approaches, stimulating the critical thinking of the student;
- takes into consideration the cultural and / or environmental context for the teaching of scientific disciplines;
- promotes online networking of schools and collaborative approaches to teaching, student-student, teacher-teacher.

The project aspires at the validation of an innovative method and at the construction of a database of exercises, problems and tasks relating to the disciplines of Mathematics, Physics and Natural Sciences, at increasing students' skills, as well as sharing results with fellow students also within the entire European community. For teachers, the expected result of the project is to use "Do Well Science" within their own teaching practice as an aid to strengthening and deepening the disciplines.

The use of the platform and applets will enable the student to obtain rapid positive results, since in a short time they will be able to solve a type of exercise or problem, with gradually increasing degrees of difficulty. The use of the platform and the applets can also be done during the lesson, if there is need for an immediate upgrade, otherwise postponed and therefore the student remains in difficulty for the rest of the lesson.

Teachers will be able to advise individual learners on certain exercises that will have the solution, either step by step, or with closed questions or open questions. The optimization of time in the classroom is favoured, as is attention and results.

1.5. References

[1] OECD 2018 - PISA 2015 in focus, www.oecd.org/pisa/pisa-2015-results-in-focus.pdf

[2] Eurydice statistics, webgate.ec.europa.eu/fpfis/mwikis/eurydice/index.php/Publications

[3] #EuFactor project, www.nextadv.it/project/eufactor-il-genio-e-dentro-di-te

[4] INDIRE - Italian National Institute for Documentation, Innovation and Educational Research, www.indire.it

[5] Italian National Digital School Plan – PNSD www.miur.gov.it/scuola-digitale

[6] EU STEM Coalition, www.stemcoalition.eu

2. Literature review on STEM education

by Massimo Amato, Emanuela De Negri, Jan-Eric Mattsson, Ann Mutvei, Anna Siri

2.1. Students motivation for STEM

The focus of the presentation in the conferences like ESERA1 and IOSTE2 are mainly dominated by the researchers from academic institutions and often are heavily theory-related or concentrating on the teaching of specific concepts, mechanisms or relations, and thus more rarely focused on more general principles of how to increase the motivation of students with diverse backgrounds. The aim often seems to be how to directly mediate theories instead of realizing creative environments in which the students may take their own responsibility of their learning, understanding and use of the theories taught. Further, as STEM is a very broad concept including theories, practical activities and also professions, this makes the concept unfit for the academic world of well delimited subjects.

The interest in how to motivate students for STEM in general is therefore usually found among teachers and in teacher training programs. Conferences attracting teachers and teacher trainers often include presentations of research with emphasis on the general principles usable in different subjects and in groups of students with a diverse background.

The Conference Proceedings of NSPE in 2018 [1] included nineteen contributions under the headline Enhancing Student’s Motivation. Most of these focused on the limited theoretical areas and might rather be regarded as descriptions of teaching strategies, but some of them were presentations of more general ideas of how to enhance student motivations in general, for example:

- Van Hecke [2] showed how the Fibonacci sequence appears in architecture, in nature and music and may be used to stimulate student’s enthusiasm for STEM;
- Reynolds [3] used Creative Thinking Workshops to challenge students to apply Science to solve social problems;

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[1] ESERA, European Science education Research Association, www.esera.org, was formed at the European Conference on Research in Science education held in Leeds, England, in April 1995. It is one of the largest organizations within this field with about 1500 participants in the biennial congresses.

The aims of ESERA are to:

- Enhance the range and quality of research and research training in science education in Europe.
- Provide a forum for collaboration in science education research between European countries.
- Represent the professional interests of science education researchers in Europe.
- Seek to relate research to the policy and practice of science education in Europe.
- Foster links between science education researchers in Europe and similar communities elsewhere in the world.

[2] IOSTE, International Organization for Science and Technology Education, www.ioste.org, was established to advance the cause of education in science and technology as a vital part of the general education of the peoples of all countries and to provide scholarly exchange and discussion in the field of Science and Technology Education.

Its origins can be traced to a Symposium on World Trends in Science education convened in August 1979 in Halifax, Nova Scotia, Canada. At the third symposium, held in Brisbane (Australia) in 1984, the informal circuit of 'World Trends' was transformed into a formal organization with members from over sixty countries.

Today, IOSTE has members from about eight countries, and is officially recognized by UNESCO as a non-governmental organization. Membership of the International Organization for Science and Technology education is open to all who subscribe to its Constitution. About 200 persons participate in the biennial symposia.

- Ailabouni & Lachish-Zalait [4] used multi-disciplinary Science-focused Theme Based Learning (TBL), a development of Project-Based Learning (PBL) for teachers of all disciplines in 7th to 9th grades.

To stimulate students' motivation to study Science and implement the scientific knowledge in real life, Colibaba et al. [5] developed activities and tools to increase the students' creativity, like storytelling, theatre performances, dances, etc.

Surrealistic paintings were used to stimulate teachers to create learning situations where students were stimulated to understand the reality behind an object instead of trying to reproduce the mind of the teacher [6].

Further, Hanáková showed how a score calibration method could be used for assessment motivation [7].

Franco-Mariscal et al. [8] used map puzzles to enhance students' motivation for learning the chemical elements. These seven examples from one conference show the width of methods used for enhancing students' motivation.

2.2. Teaching strategies for STEM

Under the headline Enhancing Student's Motivation in the Conference Proceedings of New Perspectives in Science education 2018 [1] also were included a number of contributions presenting teaching strategies in different subjects. Here follows a selection of them.

Ryan [9] presents different ways of using images to "create opportunities for students to more actively engage in learning, deepen their understanding, and generate new insights; critical thinking is enhanced, and interest is increased." Students need training to know how to read and interpret images. Here several strategies to develop visual literacy are presented; for example, images may be used as starting points of discussions as well as summaries of learning.

In Brazil, a project aiming at challenging students to experience some of the difficulties incurred by blind students learning botanical concepts, also increased the understanding and knowledge of the seeing students [10]. The challenge of blindness resulted in new perspectives regarding other characteristics than visual ones, especially for the seeing students. The project also resulted in a development of socio-emotional skills of empathy with blind students and in creating more careful teachers, breaking the established paradigms.

By providing an environment which increased self-efficacy and energy among students Colson & Naug [11] aimed at empowering students and teaching staff. Development of meta-cognitive skills, using real-life case studies within a directed framework, empowerment of laboratory tutors and a flexible model of course and program delivery, have in combination resulted in capable, highly skilled biomedical Science graduates.

Tinkering is a holistic way to engage people with STEM disciplines, mixing them with art and combining hi-tech material with low-tech and recycled material [12]. Knowledge is not transmitted from teacher to learner, but actively constructed by the mind. Children (6-12 years) in groups of 20 got some material and were free to play with it. The freedom to play also resulted in challenges they tried to solve- sometimes with some help. At the end of the day they usually had overcome the challenge and had built a complicated object. The program will now also include courses for teachers.

As there are multiple learning styles in the classroom, the benefits of the multimodal approach in teaching ought to be obvious. This is discussed by Borzello [13] based on the general knowledge of the different types of learning styles: visual (V), auditory (A), read/write (R) and Kinesthetic (K). The main conclusion is that the VARK modalities must be kept in mind when creating and teaching curriculum across all grades and age levels.

2.3. ICT as tools for motivation for STEM

There are several evidences that the use of ICT in school promotes engagement, motivation and learning of STEM. In general, ICT stimulates inquire-based learning, promotes sharing of ideas and data [14]. ICT also enhances STEM interest by allowing students to study subjects relevant to their lives, while increasing control over their own learning [15]. However, teachers' beliefs and attitude towards using digital tools in their teaching activities is crucial for achievement in student learning [16].

One example of using ICT in teaching activities is described by Looi et al. [17]. Using a digital platform, students collected data, shared their ideas with peers and interacted with the teacher using smart phones. With mobile technology, both inside and outside the classroom, students were more engaged and had better results on their tests compared to traditional teaching.

Ciang et al. [18] developed mobile technology further and created a location-based augmented reality (AR) environment. The AR environment showed to the students specific places to learn about aquatic plants and to share knowledge with others in enquire learning activities. These activities comprised authentic problems and defined questions that were investigated by field work, constructions, interviews, experiments and other investigating tools.

Another example of using mobile smart phones is the enquire of life cycles of the butterfly and the spinach plant by primary school students [19]. The enquire was supported by different digital tools for collecting data, creating film clip, making photos and constructive representation, as well as for making reflections before and after the activity. The authors showed that this tool enhanced student's personalized learning.

A teacher in Sweden described her work to make Science more interesting and easier to learn for lower secondary school students [20]. One example is when the students created podcasts to a class in upper primary school answering specific questions about the ear and hearing. Another example is the study of the nervous system and its reflexes.

Learning activities were done using a platform where students could share information, YouTube clip on the function of the nervous system, and photos. The national tests showed good results and the teacher concluded that tasks were easier to individualize based on prior knowledge, interest, desire and ability, by using digital tools. Also, cooperative learning was stimulated at the same time as students’ digital literacy.

Lukowicz et al. [21] showed that students wearing Smart Glasses (wearable computer glasses) to study physical concepts such as tone frequency enhanced learning and engagement.

2.4. STEM and under-achievement

The identification of the main causes of students under achievement in STEM and the related description of the groups of higher risks represents a crucial issue.

As explained in the previous paragraphs, interest and motivation play an important role for achievement in STEM [22]. There are not many investigations about the cause of underachievement in STEM specifically, but more about students’ uninterest in the subjects. Many students in school have a traditional view of Science, existing only as school subject and not coupled with their personal lives [23]. One way to enhance the motivation to study STEM subjects is with the use of authentic learning, including problem solving in authentic situations, the construction of knowledge together with others, the observation of and reflection on student’s learning and the teachers coaching and scaffolding, as well as authentic assessment [24]. Attempts to create authentic exercises connected to environmental questions and to other issues in real life to engage students in school, have been described in several articles [22] [23] [25]. This kind of exercises will enhance student´s STEM literacy, the knowledge of scientific concepts and processes for decision making and economic productivity [25]. STEM-literate students usually also have skills to solve problems and to argue for their decisions based on scientific, technological and mathematical knowledge. To reach STEM literacy of school students, teachers have to:

- foster self-determination,
- cultivate self-regulation,
- capitalise collaborative social goals,
- establish an engaging classroom environment.

This includes problem solving of authentic activities in cooperation with others and reflections on learning [26].

One cause of underachievement in STEM subjects by students in school might be due to the general favouring of verbal and written capacity, while students having other important skills for STEM will not be noticed properly [27]. Since most school assessments are based on written or verbal skills, students with visual-spatial ability important for creative productivity in STEM and scientific theory development, will be regarded as low achievers [27]. Visual-spatial skills are valuable for creating mental representations of complex ideas to form new model and theories which are important for STEM. Students with visual-spatial skills are learning by observation to see the whole before the parts and think in images before putting words on their thoughts [27]. Thus, it is important in STEM subjects in school to have a variation of assessments to discover other skills than traditional verbal abilities and give creative students the possibility to present their, and maybe unorthodox, solutions.

Another reason for creating low-achiever is the direct relation between the low successes of students in examinations and tests resulting in low-marks. This is often a result of disciplines arduous to teach where very few of the students are properly trained in finding and trying different paths to problem solving.

Formative assessment giving students feedback during the learning situations has been shown to be important for the development of the capacity of lower achieving students, since they have the possibility to continuously improve their results rather than getting a final mark [28].

2.5. Student background - interculturality

Students' background is a very important issue for the profession they will choose for their future. Their high education is one of the most important choices that they had to make and do with efficiency and advantages. Within STEM professions, certain groups of students are underrepresented, thus having a lower representation than the proportion of the general population. Several factors are important when students choose which education they will continue. For example, if students' intellectual capacity is negatively judged by some teachers it may influence their interest in STEM school subjects.

Explanation for the underrepresentation of certain ethnical groups is also the lack of intercultural comfort and ethnic identity in STEM professions due to different cultural values. There are also environmental and contextual factors such as perceived barriers, discrimination, stereotyping threat and low sense of belonging [29].

Other students' group less represented in STEM careers are females. Both intrinsic factors such as self-concepts and external factors such as parents, media and educators have been described to influence the choice of education in STEM [30]. Social and environmental factors, school climate and the influence of bias are three factors responsible for female underrepresentation in STEM-career. The reasons for this could be: females get less encouragement from teachers and parents, few female role models, stereotyping and less family friendly flexibility in STEM professions [30, 31]. International tests have shown females perform less in Mathematics and Science in school compared to males depending on bad self-confidence in Mathematics. This will affect female STEM career attainment, since good achievement in both Mathematics and Science is important for the professional future for both males and females [30].

The importance of parents' and teachers' encouragement of male and female school students to continue STEM careers is well established [30, 31]. Research has shown that perceived support in early school years influences male and female differently. Male achievements in Mathematics increased more in later school years upon perceived support from parents in early years compared to female. However, no relationship was seen between perceived parent support at early age and Science achievement during later education for male or female students, only for achievement in early school years independent of gender [30].

The solution to increase underrepresented groups in STEM profession would be to form strong beliefs about their abilities in STEM subjects in school by teachers, parents and career development professionals [29, 31]. Teachers should also create an atmosphere of curiosity and avoid situations that promote stereotypes. It is also important to notice positive role models [31]. Further, it has also been shown the importance of integration of different languages by multicultural students in practical exercises in Science to motivate students for STEM studies [32]. The Content and Language Integrated Learning methodology, CLIL, was proved to be a suitable approach for enhanced learning in STEM. Students were interacting in foreign and native languages and acquired knowledge in STEM, as well as enhanced language awareness and discovered other cultures and increased the acceptance of migrants [32].

2.6. Conclusion: implications for a teacher

Here we refer to our own experiences as teacher educators and mainly include the results of our own research in this context.

Teacher education is important in most countries, as the general ideas about the society and how its inhabitants ought to behave are implemented. Thus, it is important that the teacher understands the function of the curriculum, its (political) background, its aims, its rules and guidelines etc. The subject content always has to be related to the expectations of society. Although referring to a British context we have found Kelly´s The Curriculum [33] useful when discussing the relations between society and its school system and in combination with the more pronounced post-modern perspective of Doll’s [34], the students get the possibility to broaden their view of the teacher profession to include aspects they never thought of before. As we here focus on STEM, also ideas within subjects included in this context also are of importance in teacher training. Thus, ideas about the teaching of Science in general [35] or within specific fields as e.g., evolution [36, 37] have to be included in teacher training programs.

In the following paragraph there are some examples of activities developed within the teacher training program based on different aspects fn the society’s needs of qualified teachers, especially in STEM.

Knowledge is rarely only a question of remembering facts but also of achieving skills to use what is learnt [38]. By performance assessments of practical skills, teachers may get better information about the knowledge of the students but also about the enhancement of the understanding of the students. This method may be used by teachers on all levels and is practised in teacher training programs [39]. Different methods of assessments have to be used to give fair results as, e.g., the mother-tongue of the students has a positive impact on some assessment methods and a negative on others [40]. Further, the different learning strategies used by students in their development of knowledge, understanding and skills, challenges the teacher to create learning situations suitable for most students to become good Science teachers, maybe without deep knowledge of a specific subject, but with a scientific overview and good tools for teaching [41]. It is also important in teacher education to cross the, even if in reality non-existing, border between the school subjects and encourage students to develop their ability to teach in a subject integrated manner [42]. In addition, teacher training programs also ought to include information about the subject content for teaching at all stages to avoid discrepancies among the subject content between, e.g., primary and secondary school. The aim of the teaching should be the development of a deeper understanding of processes rather than the accumulation of facts [43].

Simple work fields in teacher training programs may be used as models for studies performed by children at school. By letting students design repetitive field studies during sixteen months, they developed deep understanding of research. Additionally, many students showed strong emotions when returning to the sites of their investigations, some experienced their own development, in some cases towards becoming a teacher but also on a more private or personal level. The simple activity of field observations in combination with personal reflection and feedback from teacher trainers, created complicated processes beneficial for the student [44]. The achievement of useable knowledge is enhanced by close relations between teachers and students in combination with open and visible processes of the learning [45].

Observation skills of students may be developed to enhance the understanding of the theories describing the reality. The concepts Studium and Punctum presented by Roland Barthes are useful primarily when used to describe the relation between an observer and an object of art [46]. *Studium* may be regarded as “study”, a scientific method aiming at stimulating the observer to make a technical description of the work studied but also to have opinions about the aims and ambitions of the artist. *Punctum* could have nothing to do with the conscious aims of the artist but may be regarded as an unconscious reaction of the observer to something in the artwork, like an arrow shot from the picture pierces the observer and creates a wound or a scar. These different types of relations between an object and its observer may be used in teaching, especially to make the student aware of the possible different qualities of observations and the role as a subject in the relation [47]. The use of art work in making these complex relations visible may be used also in primary school [48] and will hopefully also promote active creative learning. This will include a feeling of meaningful learning, ownership of the learning, control of learning processes and innovation when new understanding is going to be realised [49].

People may exhibit different ways of seeing and representing the world, which are used in different contexts, and they have different conceptual profiles. These profiles may be regarded as different ways of describing the world, none more true than the other.

Words usually have multiple meanings, which may create problems, but also may be regarded as a possibility for creating deeper or wider understanding [50].

The theory of conceptual profiles may be used to assess learning outcomes [51], for performance assessment [52] or to compare the differences in the use of concepts in different groups of people [53].

Some specific quality markers, during the student's assessments, are useful especially when the depth of the understanding of the students is assessed both during the courses, mainly as formative tools, and also at the end of courses. The 4R, Relations, Recursion, Richness and Rigor, of Dolls are valuable [54] and they have been used in teacher training programs for assessing the learning outcome of the students, e.g., the understanding of evolutionary concepts [55, 56], the technological literacy [57], the personal development [58], the depth of descriptions regarding perception [59], or the relation between personal development during courses and the results of the examination [60].

An example of different aspects of what may be included in teacher training programs could be teachers that usually have more than twenty students with different perspectives and abilities in their groups, and the flexibility in their teaching has to be enormous. To meet that challenge, in coo-operation with their students, they need own experiences of good education. This has been presented by the teachers of the teacher training program acting as good examples of the profession [60].

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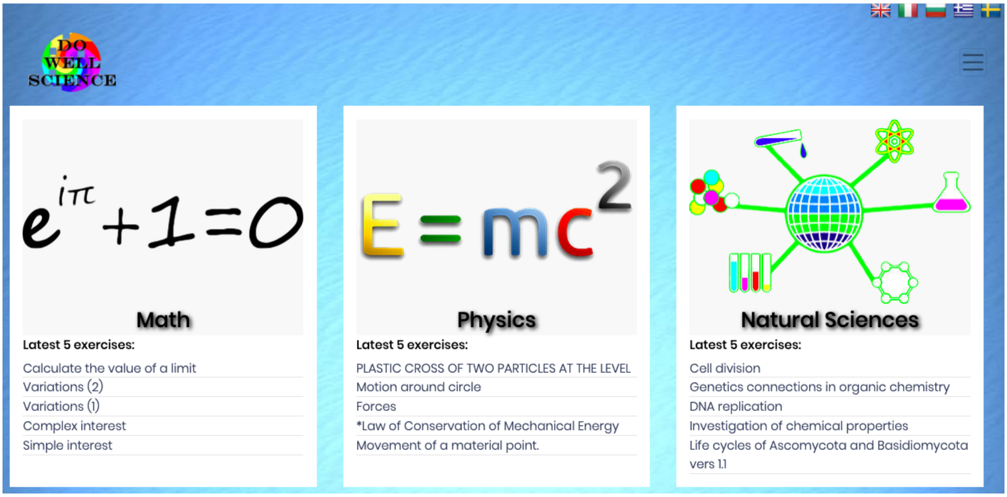
PART II

The “DO WELL SCIENCE” European project

Erasmus+

Project number: 2017-1-IT02-KA201-036780

www.dowellscience.eu



iOS app

Android app

apps.apple.com/it/app/dowellscience/id1326841702

play.google.com/store/apps/details?id=eu.dowellscience.dowellscienceapp&gl=IT

1. The “Do Well Science” Project

by Massimo Amato, Nikolaos Giannakopoulos, Milena Gosheva, Nikolia Iliopoulou, Emmanouil Petrakis, Greta Raykovska, Georgios Theodoropoulos

1.1. Introduction

The teaching of Science subjects is as important as it is difficult in the light of new discoveries and new teaching methods where teachers are called to further involve students in having a systematic and effective approach in daily study.

Teaching through ICT tools is increasingly widespread and appreciated by students.

Often, for scientific subjects, publishing houses and specialized websites present exercises and tests that address the issues for a wide range of students, perhaps divided by type of school or by category of the same. However, if a teacher in a particular class needs exercises aimed at achieving certain goals, then the overview on the web drastically reduces the possibility of identifying the desired exercise or test. Furthermore, each teacher gives his or her own imprinting to the explanations, to the resolutive methodologies, with some predilections because it is he, who knows his students, who can change the method of dealing with the issues addressed from year to year but also in the same school year.

Therefore, the idea of designing a web portal with related applets for mobile devices was born spontaneously, so that individual teachers could upload exercises, problems, tests that reflect their needs and at the same time the students are encouraged to "play" to solve the exercises, problems and tests through the purchase of the score and the exchange of the same through social media. In addition, students have the opportunity to request that new exercises be uploaded.

The Erasmus + "Do Well Science" project [1] was therefore born from the idea of prof. Massimo Amato of high school "Niccolò Machiavelli" in Florence - Italy and involves the following partners:

- Liceo “Niccolò Machiavelli”, Florence - Italy (Project applicant)

  www.liceomachiavelli-firenze.edu.it
- Vocational High School of Electronics “John Atanasoff”, Sofia - Bulgaria

  www.spge-bg.com
- Zinev Art Technologies, Sofia - Bulgaria

  www.zatbg.org, www.artsbg.net
- “Arsakeio” Lyceum of Patra, Patra – Greece

  www.arsakeio.gr/gr/patra
- University of Peloponnese - Special Account for Research Funds, Tripolis - Greece

  www.elke.uop.gr

- Pixel, Florence - Italy

  www.pixel-online.net

- Università degli Studi di Genova, Dipartimento di Matematica, Genoa - Italy

  www.dima.unige.it

- Södertörn University, Huddinge – Sweden

  www.sh.se

The project partners [2] worked in teams at every stage of the realization and their personal contribution was of fundamental importance to the success of the project in every detail. While unanimously sharing the choices made during the entire project, relating only to the development of the intellectual output 1 of the project, the creation of the related web portal and applets, in short and very generally, the high schools "Machiavelli", "Atanasoff" and "Arsakeio" and the University of “Södertörn” have created the exercises and the verification tests, structured their presentation and validated them, Pixel and the University of the Peloponnese have been responsible for creating the portal and the applets for devices furniture and the University of Genoa has identified Ligurian schools that have contributed to the testing and validation phase.

The methodology of development and the creation of exercises by the teachers, their presentation to the students and the methods of performance and attribution of the score are some of the strengths of the project. A new resource for teachers aimed at their students. The teacher who creates the exercise therefore has a fundamental role for the growth of the resolving abilities of their students. He/She must develop exercises to improve his/her students.

1.2. Project Objectives

The main objective of the project is to have a platform to learn scientific subjects using the tools that are the most used by students today, and not only by them: phones and other mobile devices.

Performing and learning to perform exercises, problems and tests in Biology, Chemistry, Physics and Mathematics, perhaps inserted on the web by the teacher who carries out the lesson from the curriculum, using his own telephone is a way of making school attractive for the student and at the same time more immediate and easier to find.

The "Do Well Science" project requires that a single exercise be included in at least one form of presentation among those possible, Explorer, Navigator and Investigator, and the student can use them as a review, in-depth analysis and verification, with an effective learning style and a methodology very familiar to him, which responds to his needs and recalls the ways to carry out knowledge as he is accustomed to daily.

For these purposes, a web portal [3] and two applets, for Android [4] and for iOS [5], have been created in the languages of the partners in addition to English. Both, the web portal and the applets can be used with or without registration.

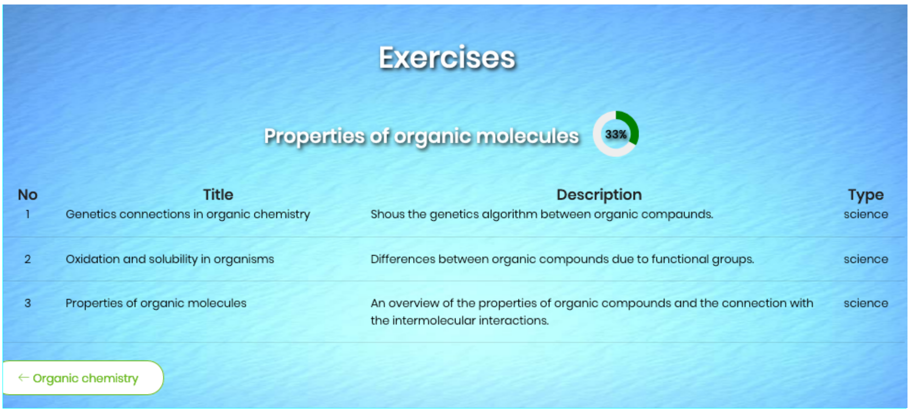
In case of registration [6], for students the portal allows the memorization of the score and its sharing with social media, the possibility of requesting new and targeted exercises and if the skills turn out to be suitable, to become a creator of content in all respects. Teachers who have an interest in entering their exercises in the portal must register and enter their first exercise which will be evaluated before making it visible to students. Each teacher can insert his/her own exercise in the language he/she wants, but an English translation is also preferable allowing the whole community to access the new resource.

Exercises

As of today, the total number of exercises uploaded to the portal and usable by students is 208.

The categories of exercises are presented as islands and the individual topics of the various disciplines as villages.

Once the village has been chosen, the list of planned exercises appears, as showed in the figure below.



No	Title	Description	Type
1	Genetics connections in organic chemistry	Shous the genetics algorithm between organic compaunds.	science
2	Oxidation and solubility in organisms	Differences between organic compounds due to functional groups.	science
3	Properties of organic molecules	An overview of the properties of organic compounds and the connection with the intermolecular interactions.	science

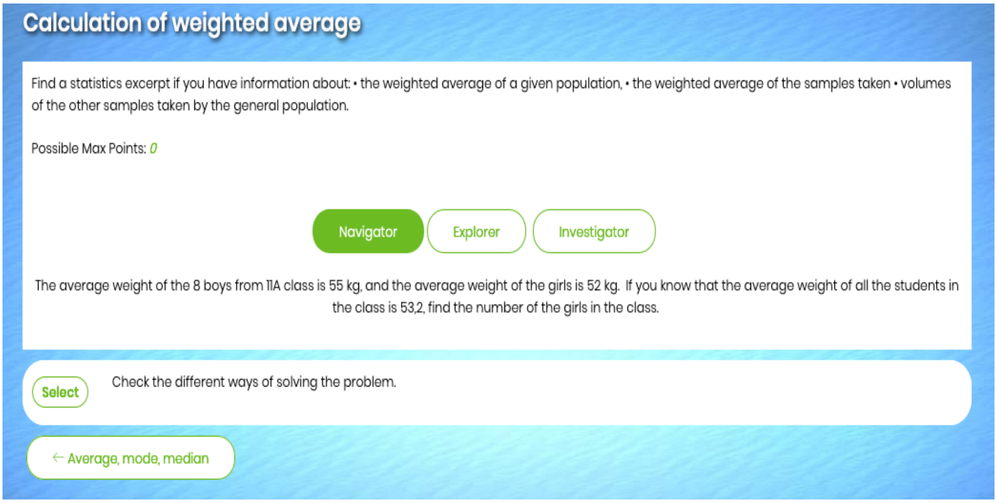
Teachers do not have the possibility to verify, evaluate or control the students' exercises, with the advantage of emotional tranquillity and therefore an increase in resolving capacity. Students can devote themselves to study with dedication and calmness, with the desire to do well and share the results with friends, in a technological environment, dynamic and more appropriate to their needs and habits.

The exercises can be presented in a combination of the three modes, Explorer, Navigator and Investigator chosen by the teacher who created the exercise. Students can earn or lose points by performing the exercises or following their resolution.

1.3. Contents’ methodology

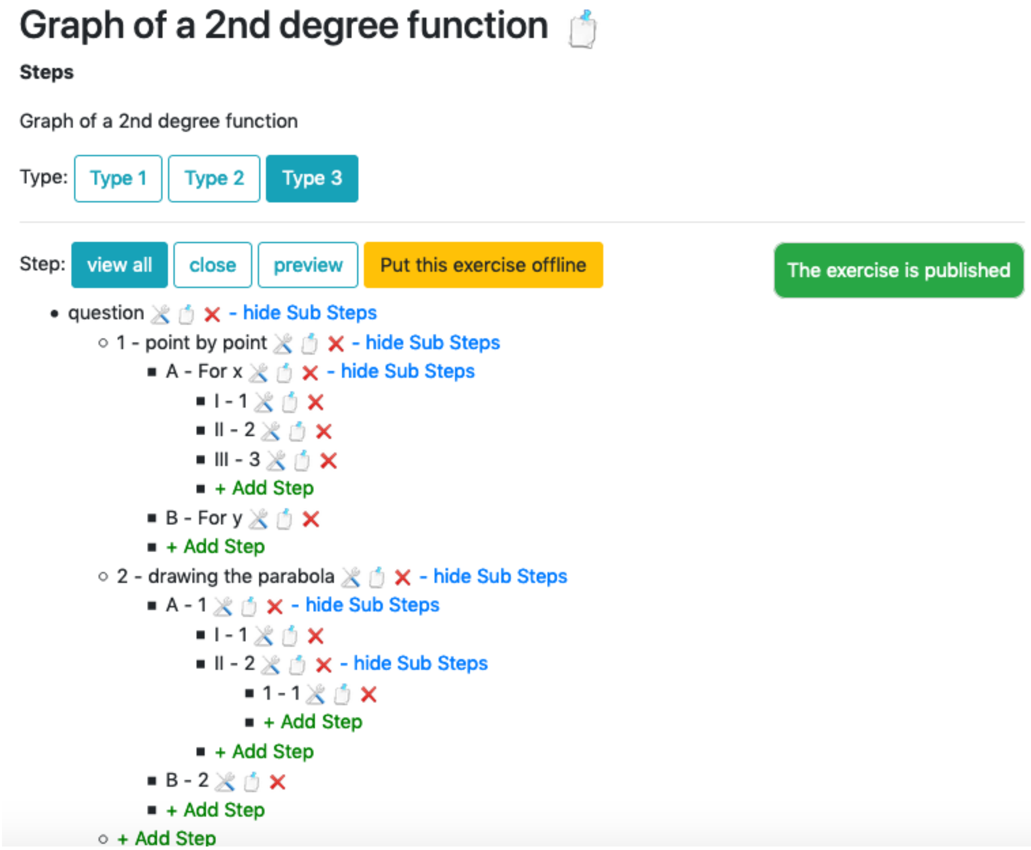
The use of the "Do Well Science" platform is designed to help teachers help their students.

The teacher has the possibility, after registering, to insert a new exercise in at least one of the three possible ways: Explorer, Navigator and Investigator.



Step by step, the teacher creates the exercise according to thier own criteria and the needs of their students.

At each step you can enter a score that will be added to the one already obtained by the student in previous exercises.



The choice of how many steps, the difficulty, the strategy and the attribution of the score is left to the teacher.

“Explorer” mode

In the Explorer version the teacher inserts the question and the various steps to solve it. There is only one resolution path. Step by step, through the development and explanations, the student is guided to the solution identified by the creator of the exercise that he considers the most valid and effective.

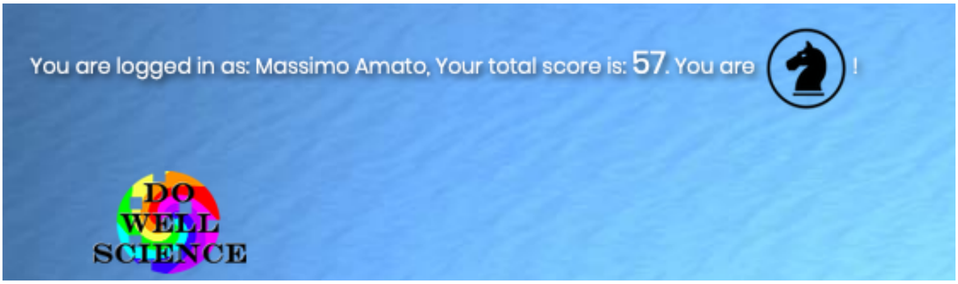
“Navigator” mode

The Navigator method allows the creator teacher of the exercise to indicate more possible solutions. The student finds himself making choices, all formally correct, but he is called to identify the most correct one that gives him the highest score.

“Investigator” mode

The creation of an exercise in Investigator mode allows the content creator to also enter wrong answers so the student, knowing the possibility, must pay attention and concentrate if he does not want to lose points.

To involve and entice the student to perform more exercises, 6 levels of use have been established based on the total score acquired, so up to 50 points, the student is classified as a Pawn, up to 150 points is a Knight, up to 300 is a Bishop, up to 600 points is a Rook, up to 1000 points is a Queen and up to 5000 points is a King. For example:



The student therefore has at his disposal a new methodology to identify and/ or search for a solution to a question and can learn through exercises, aimed at achieving certain skills that the teacher considers to increase.

The idea that must always be kept in mind is that each content creator is the one that must think and develop exercises for a typology of students that he knows, and through the platform "Do Well Science" he wants to share with his students to increase their skills and problem solving.

Students have at their disposal a platform that can be used with any device, from desktops to mobile phones, at any time of the day. The resolution of the exercises becomes easy to use, fluent, in which it is possible to linger on the explanations or to continue quickly, to dive in the different types of development of the same exercise and not lastly, to share the results with friends, thus having the possibility of creating a true and own league challenging each other.

1.4. Student participants in Bulgarian, Greek and Italian partner schools

The total number of registered and involved students in the “Do Well Science” were 1461.

This number is massive and it will be a very good starting point to create a community and not only to use the web portal and the applets.

Bulgaria

The students from high school SPGE “J. Atanasov” who participated in the exercise testing, are at the age of 14-18, in 8th-12th grades incl. Students are randomly selected and encompass participants from all the specialties in the high school. The students have a specific focus on technical sciences, and the use of the platform, created as a didactic learning tool, was intriguing. The students at SPGE “J. Atanasov” study English intensively and the testing of Science exercises in English language enabled them to check their language skills and competences. In doing so, they did exercises prepared both by teachers from Bulgaria and from the other countries involved in the project. For the students, taking part in the exercise testing, was interesting and quite entertaining. As a result, they made some important conclusions, for example how not to make mistakes in the process of solving problems and how to deal with different tasks and solve specific cases.

Greece

The students from "Arsakeio" Lyceum of Patras, who participated in the exercise testing, are at the age of 14-18, in 8th -12th grades incl. Three labs of the school are used namely the Physics, Chemistry and Biology lab where students carry out experiments. These classrooms are fully-equipped with instruments and other appliances. All the classes of the school include multimedia equipment (a PC, a projector, a screen and Internet connection) available for use in class during the lesson, following the modern methods of teaching practice. The conditions are ideal for practicing high standards of education and keeping traditions set by the Arsakeia Schools through the years. As a result, taking part in the exercise testing was an interesting and quite entertaining experience for the students because it was really innovative for them to use their mobiles in the classroom. The laboratory equipment is renewed every year and covers a wide range of experimental practices additional to those enforced by the Ministry of Education. Thus, teachers are enabled to carry out projects in the labs which contribute to the best possible understanding of the taught material, issued by the analytical program of the Ministry of Education. As a result, students and teachers came to some important conclusions concerning teaching practices, learning and assessment, infrastructure, curriculum, etc. and how to deal with different tasks and solve specific cases.

Italy

The students in Italy had been identified in high school grade, in particular scientific high school and technical high school, in particular the "N. Machiavelli" Lyceum of Florence, the "Calasanzio" Lyceum of Empoli (FI), the "A. Pacinotti" Lyceum of La Spezia, the "C. Colombo" Lyceum of Genoa, the "E. Amaldi" Lyceum of Novi Ligure (AL), the "E. Fermi" Lyceum of Genoa, the "E. Montale" Institute of Genoa and the "F. Liceti" Institute of Rapallo (GE). At the scientific high schools enrolled in the project, the students' age is from 14 to 19 years old, and at the technical school the age of the students is from 14 to 15 years old. The classes are from 1st year to 5th year of the scientific high school, and 1st and 2nd year of the technical high school. 772 Italian students registered into the web portal.

1.5. Use of the App or Web in each country

Through the administration of two non-mandatory questionnaires, it was possible to identify the use of applets and the web portal by teachers and students in partner schools in Bulgaria, Greece and Italy.

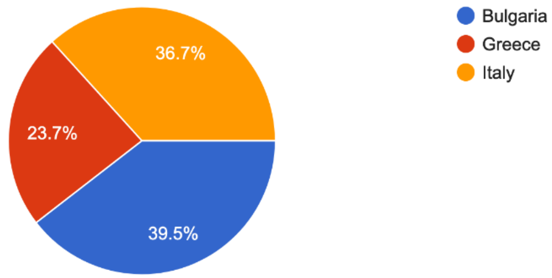
The specially developed questionnaires [7][8] provided the following indications.

Students

The free questionnaire of the students "Use of App or Web" [7], to which 215 students responded, is presented below in the questions asked and in the answers received.

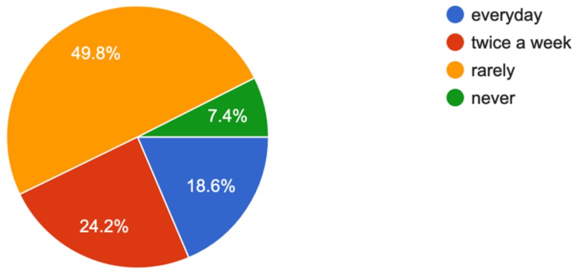
Which is your country?

215 responses

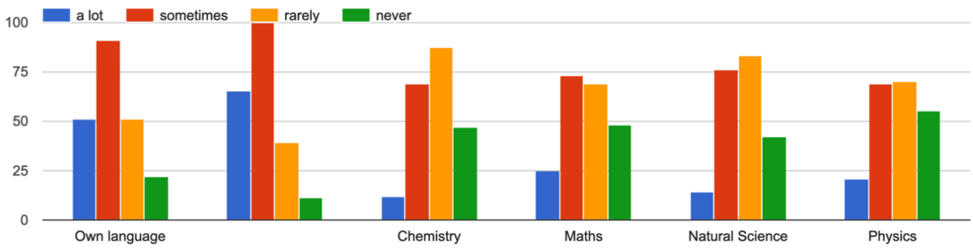


Do you use any kind of Web Site to study?

215 responses

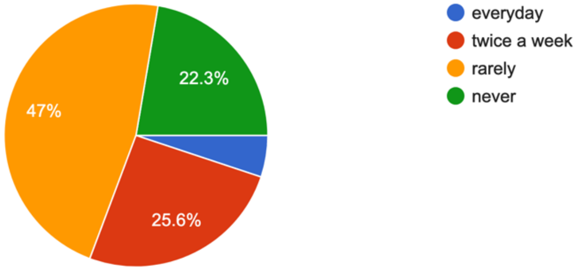


Wich kind of Web Site mainly?

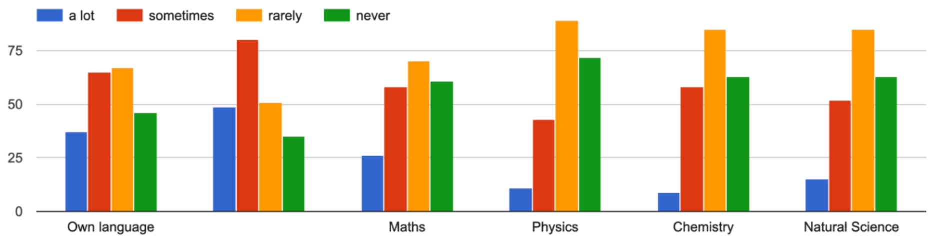


Do you use any kind of App to study?

215 responses

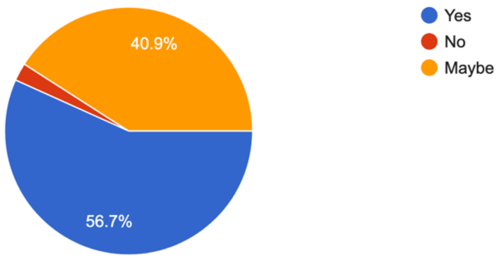


Wich kind of App mainly?

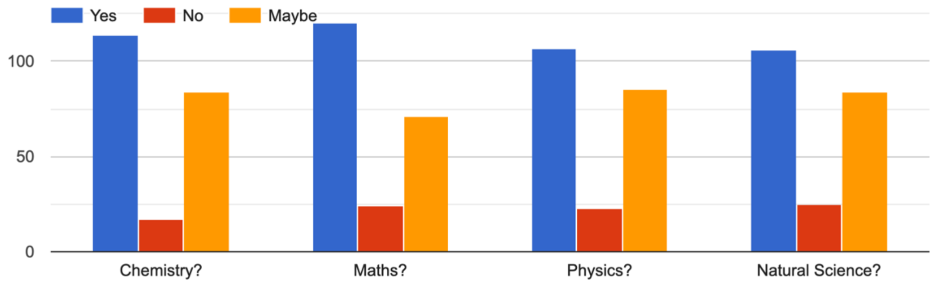


Do you think the use of apps or web portal could be advantageous for your study habits?

215 responses



Do you think that through the use of apps and web portals you can improve your skills in:



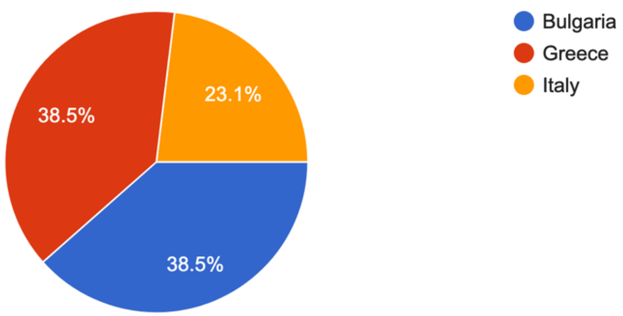
The answers provided by the students let us know that only half of them use web portals and applets to study but almost all of them think that they can help, at least in Science subjects. The "Do Well Science" project has a reason to have been developed and to be carried forward over time, so that the students benefit most from it.

Teachers

The free questionnaire of the teachers "Use of App or Web" [8], to which 13 teachers replied, even if less representative, can still be interesting to consider for the suggestions that can be drawn. Below are the questions and their answers.

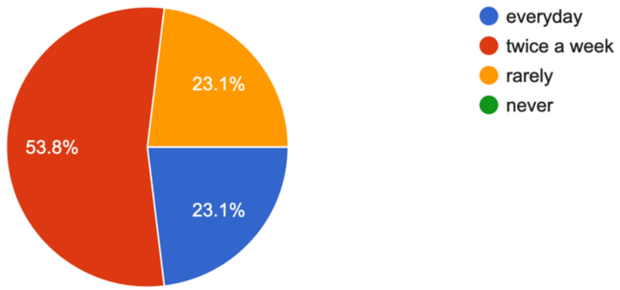
Which is your country?

13 responses

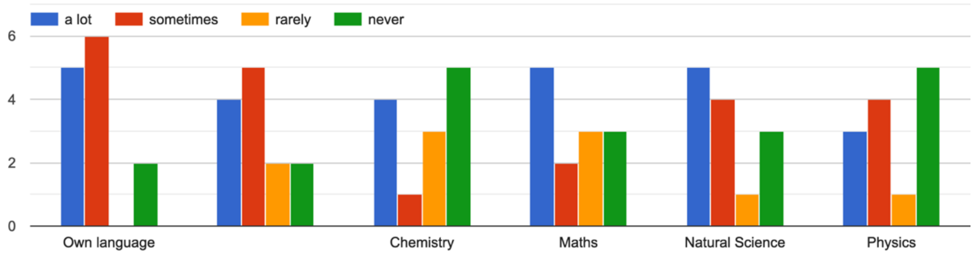


Do you use any kind of Web Site to teach?

13 responses

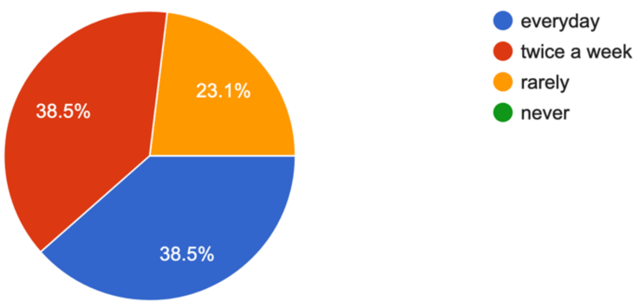


Wich kind of Web Site mainly?

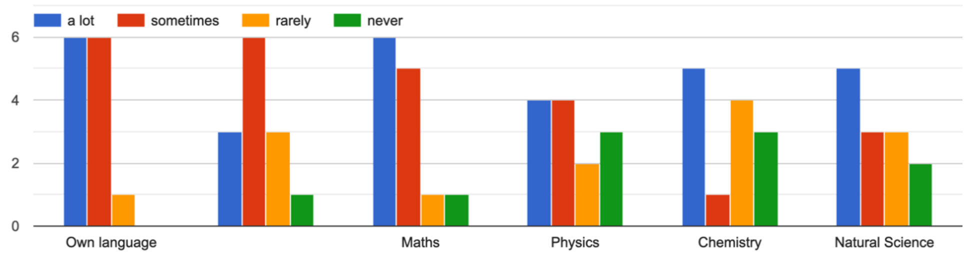


Would you suggest your students to use any kind of App?

13 responses

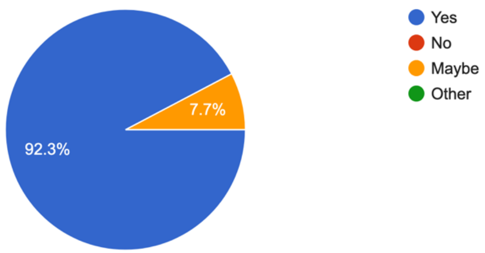


Wich kind of App mainly?

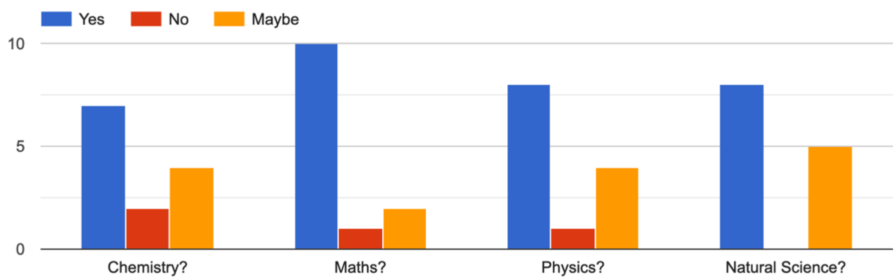


Do you think the use of apps or web portal could be of any advantages for your students?

13 responses

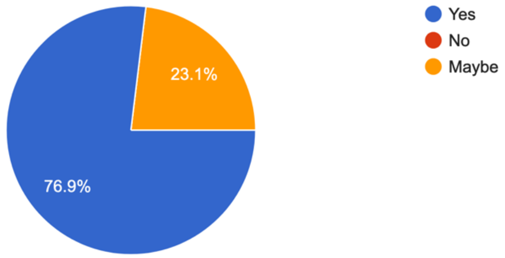


Do you think that you can improve your teaching through the use of apps and web portals in:



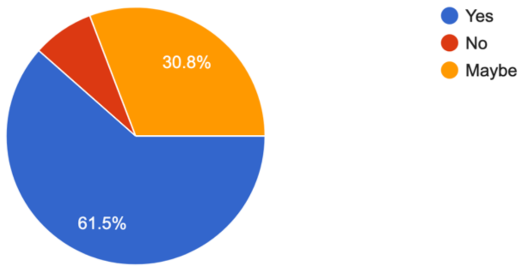
Do you think that using apps or web portal could simplify the study of students?

13 responses



Do you think that using apps or web portal could leave your students more free time?

13 responses



The teachers who answered the questionnaire say they do not use or rarely use web applications or teaching applets but all are convinced that these methodologies can be of help to their students and most likely would leave them even more free time from study.

1.6. References

[1] Erasmus+ Program Call 2017–KA2, project title: "Do Well Science", project number: 2017-1-IT02-KA201-036780, www.erasmusplus.it

[2] Project: www.dowellscience.eu/project/index.php

[3] Home-page portal: www.dowellscience.eu/ui

[4] Android app "Dowellscience": play.google.com/store/apps/details?id=eu.dowellscience.dowellscienceapp&gl=IT

[5] iOS app “Dowellscience”: apps.apple.com/it/app/dowellscience/id1326841702

[6] Registration user: www.dowellscience.eu/index.php

[7] “DWS - Use of App or Web - for Student.pdf”, appendix 1

[8] “DWS - Use of App or Web - for Teacher.pdf”, appendix 2

2. National policies on STEM in the "Do Well Science" partner countries

by Massimo Amato, Laura Capelli, Jan-Eric Mattsson, Ann Mutvei, Anna Siri

2.1. Overview

STEM as a concept is almost never used in the curricula or other important policy documents in the different countries' project but there are anyhow some STEM-related activities in all four countries. There are several international organisations promoting STEM. As seen above, Bulgaria and Greece are represented in EU STEM Coalition in contrast to Italy and Sweden.

In another international organization, e.g. European Schoolnet [1], STEM is one of the major thematic domains. Here Bulgaria is an observer country while Greece by Ministry of Education, Research and Religious Affairs [2], Italy by INDIRE - National Institute for Documentation, Innovation and Educational Research [3] and Sweden by Skolverket - Swedish National Agency for Education [4] are members.

There are several other organisations promoting STEM, but these rarely are directly related to official national educational organisations.

Bulgaria

In Bulgaria there is no specific policy for the development of STEM education but the country participates in the EU STEM-Coalition [5] through the Ministry of Education and Science [6].

According to the Bulgarian Ministry of Education and Science: "The Bulgarian education system has been traditionally supportive of STEM, providing students with numerous opportunities to broaden their experience in the STEM fields outside the curriculum. Currently, several non-government and academic organisations are responsible for the bulk of the STE(A)M initiatives in Bulgaria and most of them work closely with policymakers, trying to ensure the sustainability of their initiatives, some of which have been standing for decades and have turned into an institution of their own.

The longest standing form of extracurricular STEM activities have been the various Olympiads – Mathematics, Informatics, Information technologies, Physics, Chemistry, Astronomy, Mathematical linguistics etc. Bulgaria has been a founding member of most of the international Olympiads in these fields and last year founded EJOI (European Junior Olympiad in Informatics). Bulgaria is also one of the few countries, where students receive direct support and mentorship from active researchers. Every Olympiad has three rounds- school, district and national, with the more popular fields, such as Mathematics and Informatics also having additional national competitions. Schools are encouraged to provide extracurricular courses, preparing the students for the Olympiads through various funding programmes such as the Operative programme "Science and Education for Smart Growth".

High school research is another well-established traditional STEM activity, due to the tradition of research organizations in mentorship and access to resources to talented high school students. The High School Students Institute of Mathematics and Informatics has been functioning since 2000, initially modelling its structure and activities after the US Center for Excellence in Education and then – gradually expanding and diversifying its methods. Currently it organizes two annual high school conferences, an interview-based grant initiative supporting high achieving students to participate in international research programs, and an international summer school, which gathered 45 students from ten countries in 2017. The summer school is three weeks long and each participant is provided with a personal mentor and research topic in the field of Mathematics, Computer Science, ICT or Astronomy.

The Bulgarian Ministry of Education and Science's current priorities include:

- involvement of the three interests' parties in STEM skills intensification – kids/students, parents, school/education authorities;
- funding for STEM education innovations and interdisciplinary projects development aimed at fostering collaborations for sharing and co-creation of new knowledge among High Schools or/and Education Institutions;
- better STEM through better STEM teachers: fostering change management in education and development of education change management strategies for each High School/education institution;
- improvement and digitalisation of STEM infrastructure (STEM Labs), facilities, and libraries (digital STEM libraries at High Schools/education institutions);
- overcoming the inequality and better integration through learning communities and development of STEM knowledge map and paths (STEM BUS Bulgaria);
- pragmatism, transparency, and visibility of STEM efforts: ideas and contributions of all interest parties can be achieved through the development and sustainability of Open Data STEM portal Bulgaria;
- integration with the foreseen EIT community hub in Bulgaria" [5].

Greece

In Greece there is no specific policy for STEM education in the upper secondary education but Greece also participates in the EU STEM-Coalition [5] and is represented by FORTH, the Foundation for Research and Technology-Hellas which is one of the largest research centres in Greece.

"The Foundation for Research and Technology-Hellas (FORTH), established in 1983, is one of the largest research centres in Greece with well-organized facilities, highly qualified personnel and a reputation as a top-level research foundation worldwide. The research and technological directions of FORTH focus on areas of major scientific, social, and economic interest. The Foundation, with headquarters in Heraklion, includes six Research Institutes in different parts of the country. FORTH currently employs 1080 people (researchers, technicians and administrative staff) and trains around 320 students from Greece and other European countries.

The Educational Research and Evaluation (ERE) Group operates within the Institute of Applied and Computational Mathematics (IACM), which is one of the founding institutes of FORTH. The Group’s research concerns are in areas of educational and social innovation with particular focus on the aspects of gender, S&T, ICT, adult education and leadership in education. The scope of activity is in research for modelling and the building of understanding of the emerging social, pedagogical training and policy trends in Europe. The underlying concern is the identification of methods which can foster effectiveness in social cohesion and learning for responsible decision-making and improvement of education and lifelong learning services. This is achieved through the design and implementation of awareness development activities with the actors of the educational community, the carrying out of applied research, digital forms of course design and implementation, the conduct of programme evaluations. The Group’s research and evaluation activity is addressed under the scope of policy comprehensiveness and coherence within and across the sector of education and related sectors from a learning tradition perspective.

Over the years, the Group has developed conceptual tools to facilitate policy and tangible outputs to direct self-reflection for practitioners on matters pertinent to education and training” [8].

Italy

In Italy there is some specific policy for the development of STEM education. The most important is INDIRE [3], looking for innovation of the Italian school, which represents the key point for development into the school. It is also the National Agency for Erasmus+ programs.

The INDIRE is the reference point for educational research in Italy. It develops new didactic models, experiments with the use of new technologies in training courses, promotes the redefinition of the relationship between spaces and times of learning and teaching.

The Institute has a consolidated experience in the in-service training of teaching, administrative, technical and auxiliary staff and of school managers and had been the protagonist of some of the most important e-learning experiences at European level. Together with the INVALSI, the National Institute for the Evaluation of Education and Training System and the inspection task of the Ministry of Education, the INDIRE is part of the National Evaluation System on Education and Training [10]. In this context, the Institute develops support actions for teaching improvement processes for raising learning levels and the proper functioning in the school context.

Through quantitative and qualitative monitoring, databases and research reports, the INDIRE observes and documents the phenomena related to the transformation of the curriculum in technical and professional education, and to the issues of school and work.

Sweden

In Sweden there is no specific policy regarding the development of STEM education but the diploma goals for the Natural Science programme (upper secondary school, high-school) may be regarded as STEM policy: “The Natural Science Programme is a higher education preparatory programme. With a diploma from the programme, students should have the knowledge needed for higher education studies primarily in the Natural Sciences, Mathematics and Technology, and in other areas. The education should develop students' knowledge about context in nature, about the conditions for life, about physical phenomena and events, and about chemical processes. In Biology, Physics and Chemistry, the surrounding world is described in models that are developed in interaction between experiment and theory. The education should also develop students' knowledge of Mathematics.

Mathematics is a subject with its own distinctive character, and is also an instrument whose concepts and symbolic language is used for models developed to understand and analyse relationships in other subject areas. The education should stimulate students' curiosity and creativity, and their ability to think analytically. Through the education, students should develop a scientific approach. This covers the ability to think critically, reason logically, solve problems, and make systematic observations. Students should thus be given the opportunity to develop the skill of assessing different types of sources, and the ability to distinguish among statements based on scientific and non-scientific grounds. Understanding of sciences is based on the interaction between theory and practical experience. Experiments, laboratory experiments, field studies and other comparable practical areas should thus be central elements in the education. The education should contain a perspective from the history of ideas, which means that the ideas and theories of the sciences are studied as parts of a historical process. Students should be given the opportunity of developing their interest in science questions, and they should be able to benefit from current research findings in relevant areas. The education should give an understanding of how science and the development of society both affect and are affected by each other, and in particular highlight the role of science in questions concerning sustainable development. Students should also be given the opportunity to take part in ethical discussions of the role of science in society. Language is a tool for communication, as well as for reflection and learning. The education should thus develop students' ability to argue and express themselves in advanced writing and speaking situations related to Science and Mathematics. Students should also be able to understand, read and write about, and discuss basic Science in English. In Science and Mathematics, data collection and calculations are mainly carried out using computers.

The ability to search for, select, process and interpret information, and acquire knowledge of new technology is important for scientists and mathematicians. The education should thus provide good practice in using modern technology and equipment. The education should encourage students to take responsibility and cooperate, and further stimulate them into seeing opportunities, trying to solve problems, taking initiatives and transforming ideas into practical actions" [11].

2.2. Conclusion

Based on the diverse information, regarding structures, contents, aims and contexts produced in the different countries and presented in the previous paragraph, it may be difficult to present just and objective comparisons between the policies of the countries included. From another point of view, the resulting knowledge and skills of the individual students appears to be fairly similar. Thus, it may not be important to compare the content or the structure of the goals presented in different documents or found in other sources but to try to evaluate the outcome of the education in each country. However, this is not the objective of this presentation.

Still some questions remain: Why do we have these similarities in the outcome of the teaching regardless the differences in the curricula? The subject content is similar, at least in a wide perspective; although the main principles are learned through different examples, pedagogy, etc. is used.

Focusing on STEM, there are some immediate similarities. The STEM concept is rarely used directly in the national context. This may partly be due to the acronym itself. The word "science" in English is "ɥаука" (nauka) in Bulgarian, "Επιστήμη" (epistimi) in Greek, "scienza" in Italian and "vetenskap" in Swedish. Only in the Italian word the letter "s" is found in the beginning. Similarly, "engineering" is "инженерство" (inzhenerstvo), "μηχανική" (michaniki), "ingegneria", "ingenjörskonst". Here, none of the word begins with an "e". Further the four words may, as it is in Swedish, belong to different groups of words. Vetenskap or usually naturvetenskap refer primarily to the theoretical subjects' Biology, Chemistry and Physics. Teknik often refer to how to do in different situations but also to more technical activities as building or construction. Ingenjörskonst is usually the professional activity of construction, which may be used as a synonym to teknik. Matematik is in Swedish a subject at school similar to Biology etc. Thus, in Swedish STEM refers to (school) subjects or theoretical areas, how to act practical in different situations and a specific type of professions. As STEM includes all these disparate areas and activities, it is not a concept easily used outside the curricular school world.

2.3. References

[1] European Schoolnet, www.eun.org

[2] Greece Ministry of Education, Research and Religious Affairs, www.elidek.gr

[3] INDIRE - Italian National Institute for Documentation, Innovation and Educational Research, www.indire.it

[4] Skolverket - Swedish National Agency for Education, www.skolverket.se

[5] EU STEM Coalition, www.stemcoalition.eu

[6] Bulgarian Ministry of Education and Science, www.mon.bg

[7] Foundation for Research and Technology-Hellas, www.forth.gr

[8] European Commission – Growth – Regional Innovation Monitor Plus www.ec.europa.eu /growth/tools-databases/regional-innovation-monitor/organisation/foundation-research-and-technology-hellas-forth

[9] INVALSI - Italian National Institute for the Evaluation of Education and Training System www.invalsi.it

[10] Italian National Evaluation System for Education and Training, www.snv.pubblica.istruzione.it/snv-portale-web/public/index

[11] Elofindalvs, www.eloflindalvsgymnasium.kungsbacka.se

3. A comparison of the STEM curricula in "Do Well Science" partner countries

by Laura Capelli, Emanuela De Negri, Jan-Eric Mattsson, Ann Mutvei, Anna Siri

3.1. General outline

Before comparing the curricula of Bulgaria, Greece, Italy and Sweden school systems and their descriptions of the Science subjects, some general comparisons between their background and their structure will be presented. Knowing the general ideas behind the curricula and their different overall structures, it is more accurate to compare them. Later, the different political determinations of the curricula are presented followed by differences in structures and in how the goals are presented in the four countries.

With these facts in mind, it may be easier to follow the comparisons between the structure of the presentations and the contents of the different subjects.

A brief content for each partner's country regarding their institutionalisation.

Bulgaria

In Bulgaria, the educational aims and content for all subjects is determined in a centralized way by the Bulgarian Ministry of Education and Science www.mon.bg [1].

All school subjects are centralized via the National Education Content Standards and are developed and approved by the Ministry. These standards outline what students are expected to know and be able to do by the end of each level of schooling (primary, pre-secondary, and secondary). For each subject there is a curriculum, developed for each grade level, defining the topics of study as well as skill objectives.

Regarding the Science subjects, the aims of the STEM education, as necessary skills and knowledge by the last year of education in high schools, can be seen below.

Greece

In Greece, the educational aims and contents for all school subjects is determined by the Greek Ministry of Education, Research and Religious Affairs – MIN.EDU www.minedu.gov.gr [2] after the introduction of the Institute of Educational Policy - I.E.P www.iep.edu.gr [3] and at the end, they are approved by the Greek Parliament.

The I.E.P. is a scientific agency that provides support to the MIN.EDU on issues regarding primary and secondary education, post-secondary education, transition from secondary to higher education, teacher training, student dropout and early school leaving. Co-operation with I.E.P. is required for every relevant initiative or action taken by the MIN.EDU departments or the agencies supervised by it.

It issues opinion, in response to relevant queries submitted by the MIN.EDU, or ex officio, in relation, among others, to:

- educational policy formulation, modernization and implementation in all types of school units;

- primary and secondary education programs of studies and curricula, school books and teaching material.

The teaching of all the subjects is based on the Cross-thematic Curriculum Framework, which sets the general principles and the curricula for every subject at each grade level.

The aims of the curricula of Mathematics, Physics, Chemistry and Biology for the upper secondary education can be seen below.

Italy

In Italy, the educational aims and content for all subjects are determined in a centralized way by the Italian Ministry of Education, University and Research - MIUR www.miur.gov.it [4]. There are three levels of school: primary, lower secondary and upper secondary or high school. The compulsory school is determined by the age of the students: all students have to attend school up to 16 years old. For a regular student's career, school is up to the second year in high school.

The curricula for every level are developed by MIUR. Concerning the high school, the last five years before university, the Italian national indications about what the teachers have to teach in STEM are described below.

Sweden

In Sweden, the educational aims and content for all subjects is determined in a centralized way but by the Government after directions of the Parliament www.sweden.se/society/ education-in-sweden [5].

The Swedish curriculum for compulsory school (year 1 to 9) also includes the pre-school class, the year before the first year of the primary school, and the recreation centre (pedagogic activities in the early mornings and late afternoons, as most pupils belong to families where both parents are working the whole day. The curriculum of the last three years before university, gymnasium, includes not only preparatory programs for university studies but also programs with more practical training and thus embraces almost all Swedish older teens.

3.2. Comparison of the curricula

The curricula of the different countries have similar structures, focusing on general principles, although the Bulgarian curriculum and the Italian usually describe the content in more details.

As an example of this, we may look at the concept of model and of modelling in Mathematics, as this concept often is regarded as important in the practical use of Mathematics, and is used in many professions to calculate or predict the outcome of different actions. If we search for the word model/modelling in the four curricula we find four different ways of describing similar goals for the teaching.

Bulgaria

The curriculum directly states the objectives in this field:

The student can:

- model with a linear or square function;
- model with equations that are linear or square;
- model systems with second-degree equations with two unknowns

Here the concept model is used in a delimited and strict mathematical sense.

Greece

The Greek curriculum doesn’t use the word model, but it refers to modelling in more general terms:

In particular, through the teaching of Mathematics, students are encouraged to be able to:

- formulate and answer questions in and through Mathematics

  Specifically, the ability to formulate and answer questions in and through Mathematics is analysed in:
  - Mathematical thinking
  - Mathematical reasoning
  - Problem solving

Here, the concept model is also used in a strict mathematical sense but with wider applications.

Italy

The Italian curricula use modelling under different headlines:

Learning results of the scientific high school:

[The students] will have to:

- …
  know how to use calculation and representation tools for modelling and problem solving;
- Scientific High School with Applied Sciences Option:
  [The students] will have to:
  …
  analyse the logical structures involved and the models used in scientific research;

Mathematics: General lines and competences:

- … objective of the study:
- the concept of mathematical model and a clear idea of the difference between the mathematical vision characteristic of classical Physics (univocal correspondence between Mathematics and Nature) and that of modelling (possibility of representing the same class of phenomena through different approaches);
- construction and analysis of simple mathematical models of classes of phenomena, also using computer tools for description and calculation;

- at the end of the educational path, the student will have studied in depth the characteristic procedures of mathematical thinking (definitions, demonstrations, generalizations, formalizations), will know the basic methodologies for the construction of a mathematical model of a set of phenomena, will know how to apply what has been learned for the solution of problems, also using computer tools of geometric representation and calculation.

In the final year the student will deepen the understanding of the axiomatic method and its conceptual and methodological utility also from the point of view of mathematical modelling.

In the Italian curricula we can see a strict mathematical approach but it opens up for a wider perspective of models and modelling.

Sweden

In Swedish curricula, seven areas of Mathematics are covered by the curriculum. A relevant area is:

Teaching in Mathematics should give students the opportunity to develop their ability to:

- interpret a realistic situation and design a mathematical model, as well as use and assess a model's properties and limitations.

In the Swedish curricula the model formulation represents a similar view as that of the Italian curriculum but in a more strict or delimited mathematical sense.

Although the large differences in their approaches and descriptions the teaching based on the four curricula may result in similar learning outcomes, even if there are some differences.

The Bulgarian text does not refer to the relation between the model and the reality it describes. The reader has to be acquainted with the concept of model as something that depicts a real situation in mathematical terms and not as a way of, for example, solving equations.

Similarly, the Greek curriculum doesn’t clearly specify an object outside the mathematical framework, although the phrase “in and through Mathematics” indicates the use of Mathematics to understand a non-mathematical context.

In the Italian curriculum, the idea of modelling, is clear in the focus on using Mathematics to understand reality and not on Mathematics by itself. This is in contrast with the Swedish goal which may be interpreted as being more focused on Mathematics than reality.

With this knowledge of aims in each country in mind, it should be possible to understand the general ideas of the different curricula in the four countries and to get some ideas of different possible interpretations of these by the teachers and students. Differences in structure and content do not necessarily lead to differences in the layout and content of the courses at school.

The indications in the country curricula is presented for each discipline interesting in this project.

3.3. Mathematics curricula

The structure of the curricula in Mathematics differs among the countries and also the subject content. Here, as for the other subjects, we follow the actual text of the curricula not the syllabi for different courses. For example, many of the detailed specifications of knowledge and abilities in the Bulgarian curriculum are similar to the content of Swedish courses according to their syllabi.

Thus, it is problematic to make comparisons exclusively out of the curricula. Further, the general structure of, e.g., the Swedish goals covers elementary mathematical courses in practical study programs (farming, carpentry, hairdressing, etc.) in which the content is on a basic level far from the objectives of, for example, the aims of the Italian curriculum which is quite similar to the syllabi of the more advanced courses in Sweden. Anyhow, the presentation of the general principles makes it possible to compare the basic mathematical ideas included in the different curricula.

Greece

The Greek curriculum mainly focuses on introducing basic mathematical principles, mathematical thinking and language and the interconnection the world of experience as a preparation for academic studies and the adult life. Thus, the main aims are to encourage the students to:

- be able to formulate and answer question in and through Mathematics;
- manage mathematical language and tools.

These abilities are mainly analysed in:

- mathematical thinking, reasoning and problem solving;
- representation of mathematical concepts, processes and relationships;
- communication and use of the formal language and tools of Mathematics.

Bulgaria

The Bulgarian curriculum is in contrast detailed in the specifications of the abilities and knowledge in different fields of Mathematics which the students are supposed to master at the end of their studies. Further, the different fields usually include two levels of knowledge and abilities, each with several mathematical goals. The main areas of Mathematics in the curriculum are:

- algebra;
- figures and bodies;
- functions and measurement;
- logical knowledge;
- probabilities and statistics;
- modelling.

Italy

The Italian curriculum includes eight groups of concepts and methods that will be the objective of the studies:

- Euclidean geometry;
- algebraic calculus, Cartesian analytic geometry, elementary functions of analysis and elementary notions of differential and integral calculus;
- mathematical tools for studies of physical phenomena;
- elementary knowledge of probability calculus and statistical analysis;
- the concept of mathematical model and the differences between the univocal correspondence among Mathematics and Nature and that of modelling;
- construction of simple mathematical models;
- the characteristics of the modern axiomatic approach compared to the classic approach of Euclidean geometry;
- mathematical induction.

In the last year of the Italian high school, the fifth, the aim is to deepen the students’ understanding of the axiomatic method and from the point of view of mathematical modelling.

Sweden

The Swedish curriculum is less specific but shows differences and similarities to the others. There are seven areas in which the teaching in Mathematics aim at promoting the ability to:

- use and describe mathematical concepts and their relationships;
- use procedures and solve standard problems;
- formulate, analyse and solve mathematical problems and evaluate strategies, methods and result;
- interpret a real situation and create a mathematical model and further use and evaluate the properties and limitations of the model;
- follow, direct and evaluate mathematical reasoning;
- communicate mathematical reasoning orally, in writing and in action;
- relate Mathematics to its importance and use in other subjects in professional, social and historical contexts.

As the structure of the curricula, and also the description of their contents differs, it may be difficult to make reliable comparisons among them. Each of the eight groups of concepts and methods in the Italian curriculum refer to or have similarities with at least two, usually three or more, of the Swedish goals. The Swedish goal about communication is the only one not directly corresponding to any of the Italian groups. On the other hand, the groups in Italian curriculum are process oriented and may be regarded as instructions to follow to increase the understanding of Mathematics while the Swedish curriculum more directly aims at the goals of the teaching. Similarly, the general principles of the Greek curriculum focus not only on mathematical thinking and skills but underlines the importance of students being able to use them in daily adult life. In that perspective, the Greek curriculum clearly relates to daily life. The Bulgarian curriculum, as presented here, may be regarded as dealing with strict mathematical Science but the detailed specifications of the abilities and knowledge, that the students are supposed to master at the end of their studies, are often related to everyday life.

Thus, despite the differences among the constructions of the curricula, it is quite possible to make consistent interpretations of their aims concerning mathematical understanding. The ability to use Mathematics in a wider context seems to be more strongly supported in the Greek curriculum compared to, for example, the Bulgarian. This may lead to similarities among the abilities of students from different countries in their strict mathematical skills but to differences in their ability to use these professionally or in everyday life.

3.4. Physics curricula

The curricula in Physics differ among the countries mainly in structure but not so much in content.

Bulgaria

The Bulgarian curriculum primarily lists the content of the Physics studies under different headlines while the others focus on the goals and aims of the teaching. In the curricula of the other countries, similar descriptions and objectives may be found in the syllabi for specific courses. The resulting teaching and learning may be similar in all countries, but detailed lists may present a mechanical view of the subject content unless it is combined with more wide-ranging aims useful for citizens in general.

Some examples may illustrate the general similarities and differences. For example, the first general goal is similar in the Italian and in the Swedish curricula.

Italy

<<… At the end of the high school course the student will have learned the fundamental concepts of Physics, the laws and theories that explain them, gaining awareness of the cognitive value of the discipline and of the connection between the development of physical knowledge and the historical and philosophical context in which it is developed.>>

Sweden

<<Teaching in the subject of Physics should give students the opportunities to develop the following: Knowledge of the concepts, models, theories and working methods of Physics, and also understanding their development.>>

Greece

The Greek curriculum has similar objectives also but here the subject content primarily is related to the use of Physics in the society.

<<The main objective of the curriculum of Physics in General Upper Secondary is the formation of educated citizens / future citizens, with knowledge of the principles and laws governing the natural world, the understanding of natural phenomena and of the technological applications of these principals and laws, but also skills for best use and their exploitation in the society. This goal is for all students / future citizens.>>

This relation between the subject and the society is also found in the Italian curriculum:

<<In particular, the student will have acquired the following skills: […] understand and evaluate the scientific and technological choices that affect the society in which they live.>>

Also, the Swedish curriculum has a similar goal for the student:

<<Teaching in the subject of Physics should give students the opportunities to develop the following: Knowledge of the importance of Physics for the individual and society.>>

Although these declarations on teaching Physics are useful for the society, the main part of the curricula focus on scholastic Physics. The subject content is similar although the Bulgarian curriculum and Swedish syllabi are very detailed and specified. The Swedish syllabi seems to contain more specific applications like Radiation in medicine and technology and Climate and weather forecast.

The Greek curricula focus on literacy in Physics and the exploitation of ideas and interconnections and the Italian one specifies also the non-mechanistic areas as Einstein's special theory of relativity, quantum Physics, the wave nature of matter, etc.

3.5. Natural Science curricula

The Natural Science are divided into two different big areas, Biology and Chemistry.

Biology

The structure and content of Biology differs among the countries.

Italy

The Italian curriculum includes Earth Sciences, Biology and Chemistry in the more general Natural Science subject with focus on "observation and experimentation". In Italy, the experimental dimension seems to always be important, both in the laboratory and in the field. This practical focus makes the students directly and practically engaged.

The teachings of Natural Science aim at giving the student the skills likely to make logical connections and formulate hypotheses based on data provided or to draw conclusions based on results obtained. They are also supposed to communicate their own conclusions using the specific language and to apply the acquired knowledge to real life situations. Similarly, it is also regarded as important to establish connections with the teachings of other subjects like Physics, Mathematics, History, Philosophy and Art, which may be developed around themes and/or figures of scientists of particular relevance in the History of Science, and also to activate collaborations with universities, research institutes, science museums and the world of work. Concerning the curriculum the Biology aims are mainly on some relations to Chemistry, especially the biochemical processes where primarily Molecular Biology is studied in depth.

Bulgaria

The Bulgarian curriculum in Biology covers five different areas:

- Biosphere (macrosystem structure and processes);
- Cell (microsystem structure and processes);
- Multicellular organism (mesosystem structure and processes);
- Biological evolution;
- Observations.

Within each of these areas, there are several goals that the students are supposed to reach. Although more clearly specified these are partly similar and coherent to the knowledge and the abilities included as goals of the teaching of Biology in Sweden.

Sweden

In Sweden, teaching in the subject of Biology should give students the opportunities to develop:

- knowledge of the concepts, models, theories and working methods of Biology, and also an understanding of their development;
- the ability to analyse and find answers to subject-related questions, and to identify, formulate and solve problems. The ability to reflect on and assess chosen strategies, methods and results;
- the ability to plan, carry out, interpret and report field studies, experiments and observations, and also the ability to handle materials and equipment;
- knowledge of the importance of Biology for the individual and society;
- the ability to use knowledge of Biology to communicate, and also to examine and use information.

Greece

The Greek curriculum also covers similar areas as the others but, as for the other subjects, the goals are clearly related to development of the understanding of structures, processes and relations among organisms.

In addition to this dynamic perspective, also research methodology, collaboration and communication and the use of Biology in society are important in the Greek curriculum:

- understanding key concepts, processes and phenomena;
- initiation in research processes;
- the goal is to create favourable conditions for ensuring interest and active participation of students in exploratory learning processes such as experimentation in the laboratory, field investigations, and implementation of small research by exploiting research methods;
- communication and collaboration;

- link to the surroundings of life.

Compared to the others, the Greek curriculum has more generalized goals and also the skills of the students are not strictly specified but presented in more general terms although these may relate to personal properties rather than strict subject content.

Bulgaria

The Bulgarian student is supposed to be able to:

- describe […] environmental factors of the environment, population, biopsy, relationships and behaviour of organisms;
- compare selected organelles and cell structures:
- modelling structures and processes at cell, organism, population, and ecosystem level.

These skills are typical for those described in the first two or three Swedish goals of Biology teaching.

The difference in the curricula is mainly due to different perspectives. The Bulgarian curriculum uses macro- to micro-perspectives in Biology as the basic framework complemented with evolutionary processes, on all levels, and methodology. Within this framework, the students are given opportunities to develop their skills in Biology.

Sweden

The Swedish curriculum starts with the eligible skills of the students at the end of the studies and specifies the knowledge content (the concepts, models, theories and working methods of Biology) in the syllabi of the different courses.

The learning outcome of these different types of curricula is similar as long as the studies aim at practical biological knowledge which they are able to apply in real life situations, which was a goal of the Italian teaching in Biology.

Chemistry

Italy

In the Italian Chemistry courses, as in Biology ones, the teaching aims are to improve the student skills of making logical connections, formulating hypotheses and drawing conclusions based on results obtained. The students are supposed to communicate their conclusions and to apply the acquired knowledge to real life situations.

The curriculum emphasises how important it is to establish connections with the teachings of other subjects like Physics, Mathematics, History, Philosophy and Art, which may be developed around themes and/or figures of scientists of particular relevance in the History of Science, and also to activate collaborations with universities, research institutes, science museums and the world of work.

During the fifth year of high school, Organic Chemistry studies are included with focus on materials of technological and applicative interest, as polymers, composites, etc., and basic concepts of the main classes of materials, as metals, ceramics, semiconductors, biomaterials etc.

Bulgaria

The Bulgarian curricula describes a number of skills that the student should master within five different chemical areas:

- classification of substances and nomenclature;
- structure and properties of substances;
- use of substances;
- chemical processes;
- experiment and research.

To give an idea of how the curriculum is constructed, here is one example from each of the different areas. As a result of Chemistry education at the end of the upper secondary level, the student:

- applies the chemical nomenclature to all chemical species compounds;
- applies rules to fill the layers, sublayers, and electrons orbits;
- describes substances with special use and basic methods for their synthesis;
- uses mechanisms to explain chemical processes;
- describes methods for determining the composition and composition of substances, as well as for their separation.

As seen from the examples above the Bulgarian curriculum describes the achieved skills of the students at the end of their education.

Greece

In Greece, the Chemistry lessons are taught in the first and second year of the high school and the students are encouraged to:

- conquer an adequate and coherent body of Chemistry knowledge, which, on the one hand, will offer them conceptual and methodological tools to continue learning autonomously, and on the other, provide the future citizens with a culture of scientific investigation of things, which will give them the opportunity to have critical and reflective management of knowledge;
- develop skills necessary for both multilateral development and active participation in the modern society, such as critical thinking, creativity, collaboration, excellence and wise use of information technologies and communication;
- cultivate values, attitudes and behaviours which distinguish the educated modern citizen and contribute positively to their progress towards the upgrading.

For the Chemistry lesson, which is taught during the last year of their studies only for students in the field of Sciences hence more emphasis and depth in:

- the conceptual part with a reduction of the corresponding descriptive and more extensive development of the central concepts;

- the practical part with skills of development implemented knowledge and problem-solving;
- promoting scientific thinking, initiative, creativity and abilities of the students;
- cultivating skills that will facilitate pupils' access to the labour market;
- social awareness with reporting applications of Science in the problems.

The Greek curriculum describes the achieved skills and relates them to the surrounding society. Chemistry is definitely not just a school subject in the Greek context; it is a theoretical framework useful in the ordinary daily life of the ordinary citizen.

Sweden

Teaching in the subject of Chemistry should give students the opportunities to develop:

- knowledge of chemical concepts, models, theories and working methods, and understanding of their development;
- the ability to analyse and find answers to subject-related questions, and to identify, formulate and solve problems. The ability to reflect on and assess chosen strategies, methods and results;
- the ability to plan, carry out, interpret and report experiments and observations, and also the ability to handle chemicals and equipment;
- knowledge of the importance of Chemistry for the individual and society;
- the ability to use knowledge of Chemistry to communicate, and also to examine and use information.

The Swedish curriculum appears as a mix of the others, with emphasis on knowledge of the subject in combination with practical skills, but also on the understanding and use of the subject content in practical life.

There are differences in structure and content of the curricula, and their explicit goals, but the students probably will reach similar levels of their knowledge content, especially in regards to their possibility to participate successfully in higher studies. If there are differences these probably will show in everyday Chemistry, which often is hidden or obscure unless specifically trained on.

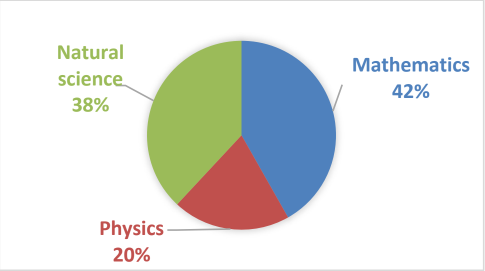
3.6. Organisation of STEM subjects

There are many differences in the school systems of the four countries involved in this study. The programs preparing the students for university studies, upper secondary school, may embrace three years in Greece and Sweden or five years in Bulgaria and Italy. The division in programs also differs, where programs with different lengths and content of courses may qualify for academic studies of a subject. The length of the school year also differs among countries and sometimes also is depending on the grade (33−40 weeks).

Considering the above information, the number of teaching hours is the most appropriate figure to use in comparisons.

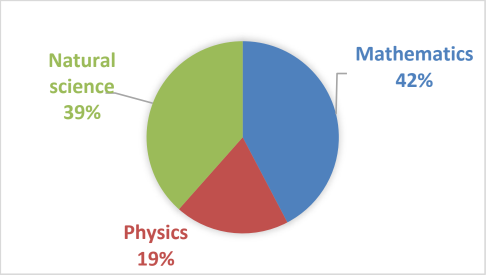
Bulgaria (5 years program)

Mathematics	303 hours
Physics	146 hours
Chemistry	132 hours
Biology	144 hours



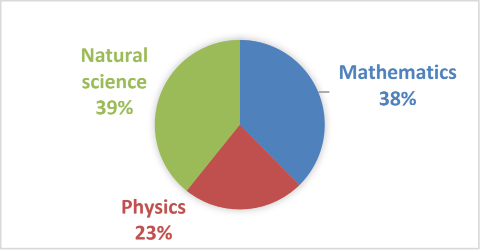
Greece (3 years program)

Mathematics	550 hours
Physics	250 hours
Chemistry	220 hours
Biology	280 hours



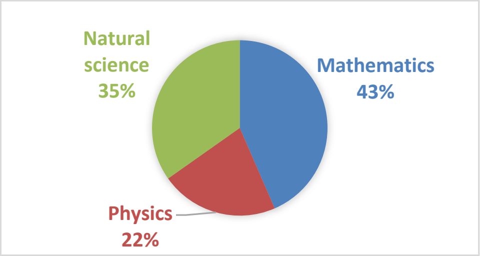
Italy (5 years scientific high school with Science option)

Mathematics	700 hours
Physics	430 hours
Natural Science	730 hours

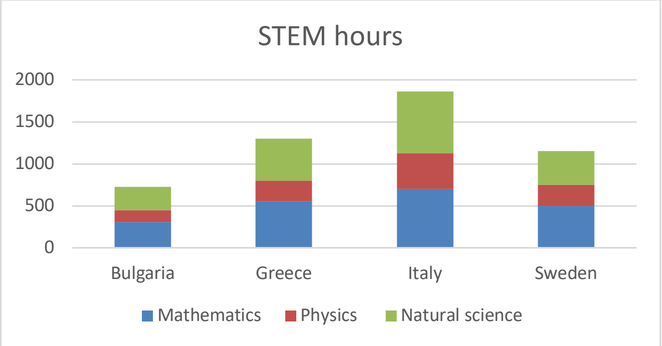


Sweden (3 years Natural Science program)

Mathematics	500 hours
Physics	250 hours
Chemistry	200 hours
Biology	200 hours



Comparing the number of STEM hours into the countries:



Regarding the students participating, in Bulgaria, Greece and Italy all students in high school study STEM subjects.

In Sweden, the Natural Science programme has about 12,000 students, about 12% of total students. The technology programme with 10,000 students, round 10%, may also include courses to prepare for academic studies in Mathematics, Physics and Chemistry. In total about on fifth of Swedish teenagers are prepared to study STEM subjects on an academic level.

3.7. Requirements of STEM for teacher qualification

In all of the project countries, the teachers have to be qualified to teach but the differences are plenty.

Bulgaria

In Bulgaria, a Bachelor school in the specific subject is needed and several mandatory courses in, for example, pedagogy, psychology, IT. This includes methodology in teaching and learning the subject as well as school observation, school practice and an internship. Bachelor’s degree courses emphasize knowledge of the subject matter, pedagogical preparation, and practical school experience. Some universities offer a degree for teachers only in one subject area (e.g., Mathematics, Biology or Chemistry), but most offer combined double undergraduate programs (e.g., Physics and Informatics, Physics and Mathematics, Chemistry and Physics, Chemistry and Informatics, Biology and Chemistry, Biology and Geography, and Mathematics and Informatics). Double degree programs culminate with a state examination in both subjects (e.g., Chemistry and Physics, Biology and Chemistry, or Physics and Mathematics). Master’s degree programs in general are designed for actively employed teachers, but they also are open to applicants who are not actively teaching. There are five levels of postgraduate professional qualification for actively employed teachers in Bulgaria, the first level being the highest and the fifth the lowest. These qualifications are not mandated and can be completed at any time at the teacher’s own discretion. The requirements for completing each level are nationally regulated. The qualifications are conferred by the Departments for In-Service Teacher Training, affiliated with three of Bulgaria’s universities.

Greece

In Greece, the degree after four years of university studies is a sufficient requirement for teaching. For teachers teaching for the first time, there is an introductory training seminar organized by the ministry of education.

Italy

In Italy, state requirements for teacher qualification include a master/bachelor in Maths or Physics or Biology/Chemistry/Natural Science or Engineering. After this graduation, it is possible to become high school teachers through a state competition or further two years of specialization with, also the interested in STEM disciplines, courses on pedagogy and sociology.

Sweden

In Sweden, the STEM teacher qualification includes five to five and a half years of academic studies. The studies include subject studies of three and a half years, the core of education Science in one year, and a further half year of practical work at schools. The different courses may be spread out over several semesters which will result in a mixture of theoretical, pedagogical and practical courses during the training. The subjects studied normally include two subjects, usually Biology/Chemistry, Biology/Mathematics, Biology/Natural Science (Chemistry, Physics, and Earth Science), Physics/Mathematics, Geography/Mathematics or Chemistry/Mathematics. One of these subjects is studied during two years, the other during one year and a half. The core of education Science includes the history of the school systems, the present school organisation, basic democratic and human rights, curriculum theory and didactics, theory and research, development, learning and special education, social relations, conflict handling and leadership, assessment and grading, and finally evaluation and development. The practical courses are often spread over time in the program to increase the teaching ability of the student and adapt the training to the personal requirements of the student.

3.8. Conclusion

As seen already in the introduction of this chapter, there are several differences in the structure of these curricula as well as in their contents. Also, the aims or goals seem to differ, but mainly due to the different perspectives of the curricula. It is anyhow possible to acknowledge the possibility of similar results concerning the preparation for higher studies in the development of theoretical understanding and practical skills of the participating students. If there are differences in the resulting knowledge and practical skills of the different subjects, these may probably mainly appear in the practical everyday life of the student. It may be important to learn the lesson of the Greek curriculum and never forget to relate the subject content to everyday life whenever this is possible.

School Science may be adequate in school situations but learning should also be learning for life, not only for school. In combination, these curricula show the necessity of the teacher to use several ways of describing goals, to vary the way of teaching and use the individualities of the students. To facilitate this and widen the perspectives, every teacher should not only be accustomed to the curriculum and syllabi of the own country but also of these of others.

3.9. References

[1] Bulgarian Ministry of Education and Science, www.mon.bg

[2] Greek Ministry of Education, Research and Religious Affairs – MIN.EDU, www.minedu.gov.gr

[3] Greek Institute of Educational Policy - I.E.P, www.iep.edu.gr

[4] Italian Ministry of Education, University and Research – MIUR, www.miur.gov.it.

[5] Swedish Government after directions of the Parliament www.sweden.se/society/education-in-sweden

4. Web portal & app Project development

by Massimo Amato, Nikolaos Giannakopoulos, Milena Gosheva, Nikolia Iliopoulou, Emmanouil Petrakis, Greta Raykovska, Georgios Theodoropoulos

4.1. Introduction

The development of the portal and applications for mobile devices has been carried out in different phases. After the implementation of the portal and the app as well as the related debugging phase, it was necessary to carry out a testing phase so that students and teachers who were not initially involved in the project had the opportunity to help partners optimize the content and support the creation of methods for the exercises by the teachers and their use by the students. Therefore, questionnaires were specifically designed to be given to teachers and for them to verify the use of the portal and applications.

The development of the portal in its forms shared by the partners was tackled by following the ideas of gamification and approach to the STEM disciplines as specified in Part III of this manual.

The contents of the portal and how they were designed and prepared are presented below.

4.2. How and which exercises are developed by partners

During the first meeting, the partners decided which kind of exercises they should have developed, in terms of number, typology and different schools whom the partners were.

Following the idea of the project, shared by all the partners, each exercise could be created and developed in three modalities named "Explorer, Navigator and Investigator".

In the Explorer mode the exercise is showed with only one right solution. This solution is developed by the teacher that should foster a specific scientific skill in the students in a very short time, depending on the kind of exercise.

By Navigator modality the teacher could insert in more than one right solution, thus growing the skills of the students and their curiosity by following and exploring different ways to resolve an exercise.

When the same exercise is developed in Investigator mode, the student has to select the right answer in a range of possibilities so as to learn the solution in depth.

The total number of exercises developed by partners is 208.

The figures show the types in percentage developed by each partner.

"Atanasov" (BG)

The exercises developed by SPGE "J. Atanasov" in Bulgaria are in the field of Natural Sciences, Physics and Mathematics. The exercises were distributed among 10 teachers in the following way: 55 exercises in Mathematics, prepared by 4 teachers. They cover the following topics: square equations, equations of a higher degree, fractional equations, irrational equations, inequalities, systems of equations, probability theory, and limit of functions.

The exercises in Physics are 17 in number, distributed among 3 teachers. They include mechanics, fluid mechanics, forces, Energy, the laws of conservation of energy and impulse, strike between bodies. Part of the chosen exercises in Physics is taught during the preparation of the students for continuation at a higher technical school. The choice of such exercises is due to the fact, that the students from our high school continue their education in higher technical schools and Physics education is leading.

The exercises in Natural Sciences are 17, 9 of which are in Biology and 8 - in Chemistry. The topics are in the fields of Genetics and Ecology, Organic Chemistry, and the bonds among chemical elements. The exercises are developed on the basis of the suggested and approved topics of exercises by all partners. The choice made by the high school teachers from SPGE "J. Atanasov" is accordant with the students' basic knowledge and skills, and the developed exercises enable them to upgrade their knowledge.

The are three types of exercises, so that the students can learn about the possible ways to solve a problem or a task, and also to make a choice on how to solve the problem or the task and to see the possible mistakes they can make, if they fail to follow all the successive steps in doing the task.

The type 3 of the exercises is of a training character, because the students directly see where they can possibly make mistakes and learn from them, trying not to make them in other exercises.

"Arsakeio" (GR)

Greek partners developed their own exercises. During the first meeting, the project coordinator indicated the categories of these exercises and the number of exercises per category and the partners approved. The exercises included in the project are in the field of Mathematics, Physics and Natural Sciences.

A total number of 21 exercises were created by the Mathematics teachers of "Arsakeio" Lyceum.

These exercises were chosen for several reasons. First of all, they are considered to be representative of the respective categories, as similar exercises are found in pupils' school books in upper secondary education in Greece. Furthermore, it is possible to solve these exercises in two or more ways which corresponds to the general philosophy of the platform's operation. Finally, it has been proven that students have difficulty in understanding the resolution process in several of these exercises if it is presented to them in the traditional way. This is an opportunity for the students to work on their own through the platform, by choosing the most appropriate way or the best method that will enable them to deeply comprehend these exercises.

The exercises in Physics were distributed by one teacher. They include 12 exercises. More specifically, the physics issues undertaken by the partners in Greece are based on the initial allocation made by the program coordinator and the selection of these exercises was done according to the educational program applied in Greece. The exercises cover a wide range of the material taught from the third grade of the Gymnasium to the third grade of the Lyceum.

In all the suggested exercises, the questions are of increasing difficulty. Finally, we have chosen the types of exercises, one and three, because we believe that these types of exercises are more acceptable to the pupils and are more suited to the current educational system.

The exercises in Natural Sciences were distributed by two teachers and are in total 11, seven of which are in Chemistry and four in Biology. More specifically:

- Chemistry: The topics are in the fields of periodic table of the elements and the investigation of chemical properties (such as atomic mass for example), chemical stoichiometry and organic Chemistry. The exercises are developed on the basis of the suggested and approved topics of exercises by all partners. Additionally, one exercise was prepared in Greek language and the language test needed to be performed by the contributor of the app. Between the three types of each exercise, it seems that the third type (explorer) best suits Chemistry because the students directly see where they can possibly make mistakes and learn from them, trying not to repeat them in other exercises.
- Biology: As far as the Biology exercises are concerned, in total six exercises were created, five of them in English and one in Greek. Exercises were selected from the following thematic sections: Genetics, Phylogeny, Ecology and Molecular Biology. The exercises were created for students of all high school classes. The choice of exercises was based on students’ cognitive background and all three types were designed to test their knowledge in an interesting way beyond the teacher-centred teaching standard. Especially, the third type of exercises managed to keep students motivated during Biology class.

“Machiavelli” (IT)

Italian partners developed their 44 own exercises following the project indications, so the Italian teachers provided exercises in Chemistry, Mathematics and Physics according to the needs and the possible requirements of the students. The teachers involved in the project had some meetings to focus on which kind of exercises and of which typology to be included. The teachers preferred to extend their work to the most students possible, so they choose to write the exercises in English. Some exercises are in Italian just to help the objectives of the project. Consequently, the decision was to create several exercises for the first, the second and third classes of the Italian high school.

In Mathematics the exercises’ number is 18, in Physics is 11 and in Natural Sciences 15.

“Södertörn” (SE)

Swedish partners developed their own 28 exercises concerning the evolution of the natural systems. This kind of exercises has been due to the type of university departments from which the teachers are coming. Evaluating the modality of the presentation of the questions the teachers mainly limited to the “Investigator” mode, because it is the best fit for the type of examination that the students are called to do. After a very brief time where it was necessary to understand how to create and why, the teachers developed the exercises with enthusiasm and proficiency.

4.3. Development of the web app correlated to the student test using the settled survey

During the development of the project, the partner would know the indications of the users to take care of those at the moment or in the future,after the project.

The partners asked their teachers to confront the idea and the methodology of “Do Well Science” with their students, using the items and answers to the surveys, to test the web portal and the app.

Predominantly the attention is the project but “Do Well Science” had also been an opportunity to understand the students’ interest in STEM approach.

Students and teacher were called to answer a survey so as to know their relation to the project.

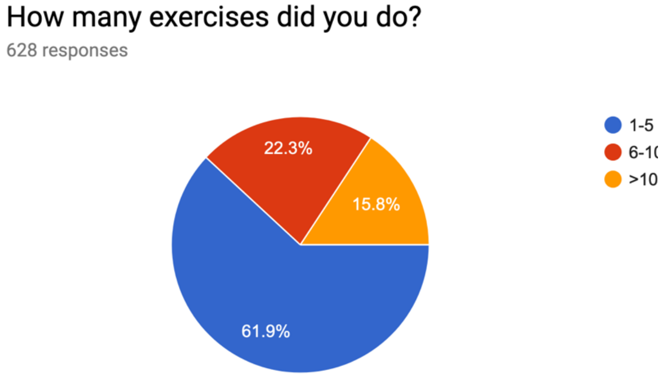
Students

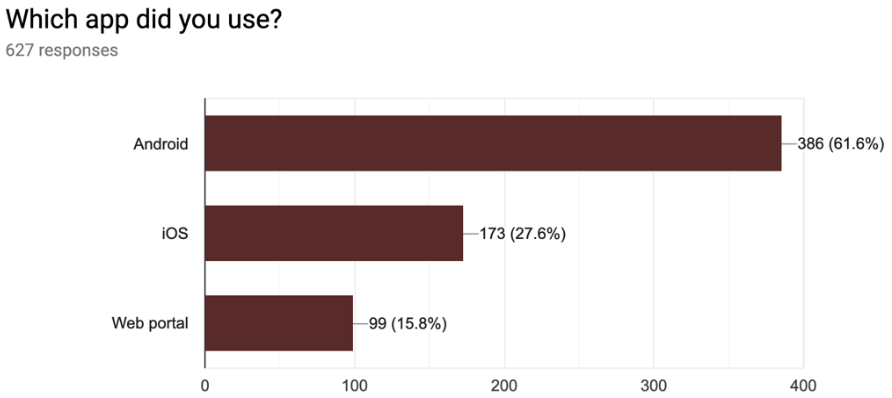
The surveys presented below were non-compulsory, because the project would have a response from the students without any kind of suggestion, so the answers could be very interesting as they are.

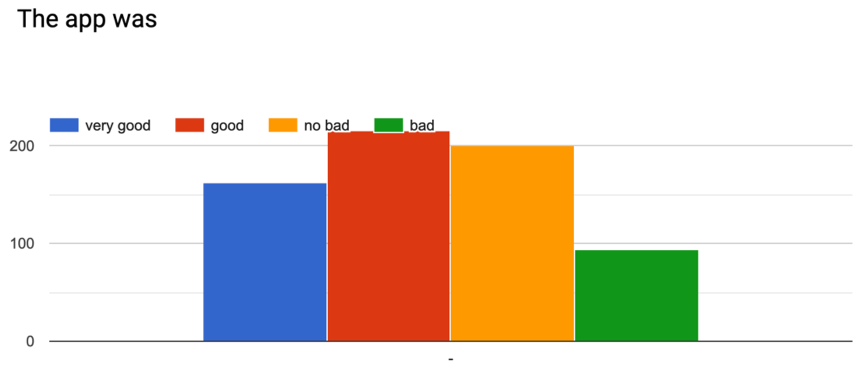
Using the data collected with the “DWS - Student questionnaire” [1]:

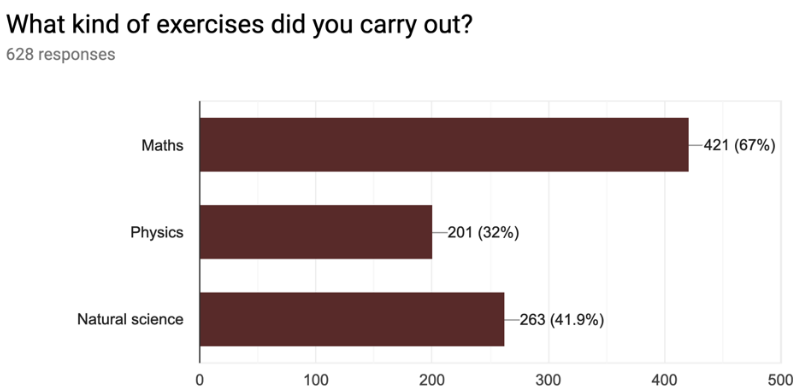
- 628 students filled in the survey in which they could answer about which kind of app they used and how many exercises they tested.

The graphics of the portal and applications for iOS and Android are very pleasant and interesting. The same graphic also allows teachers to make the presentation of new exercises more appealing, since some subjects are often difficult to introduce.



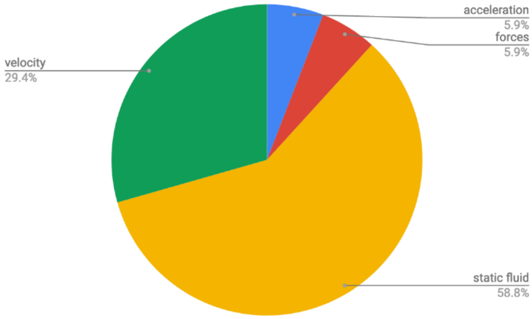

Which app did you use?
627 responses
Android
386 (61.6%)
iOS
173 (27.6%)
Web portal
99 (15.8%)
0
100
200
300
400


The app was
very good
good
no bad
bad
200
100
0
-


What kind of exercises did you carry out?
628 responses
Maths
421 (67%)
Physics
201 (32%)
Natural science
263 (41.9%)
0
100
200
300
400
500

Using the data collected with the “DWS – Exercise suggestion” questionnaire [2]:

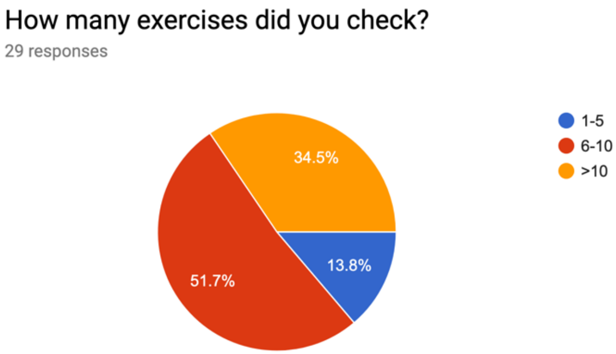
- 12 students, from Bulgaria, filled in the survey indicating new exercises only in Physics.

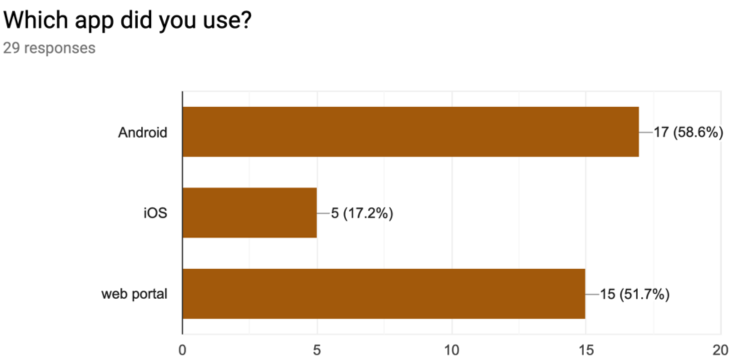


Teachers

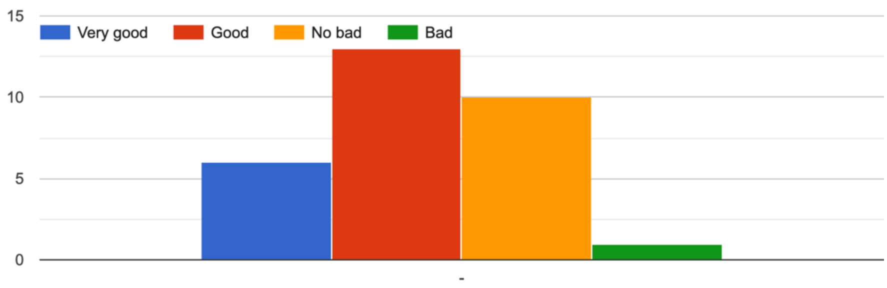
The total number of teachers who tested the app were 37, 29 by the online form [3], and 8 by hand-writing form [4].

Using the answers of the survey “DWS – Teacher questionnaire.pdf” [3], the results are:



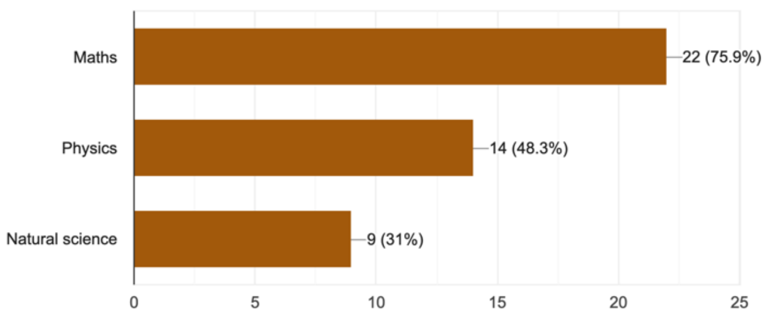


The app was

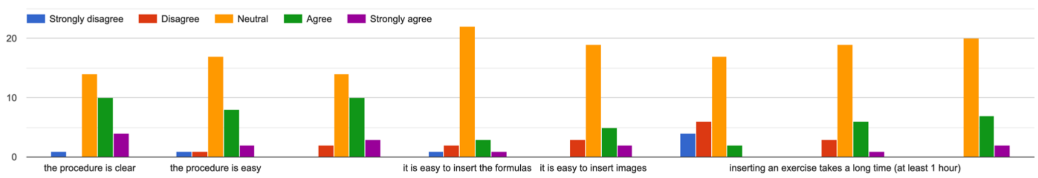


What kind of exercises did you carry out?

29 responses



If you create any exercise ...



Using the answer of the hand-writing form [4], the result is:

- for the question “STEM Teaching and Learning Package”
  - general organization of structure: 8,6%
  - easiness of navigation: 8,6
  - scientific reliability: 8,6
  - didactical Appropriateness: 8,2

    - usefulness and Transferability: 8,4
    - attractiveness for students: 8,4
- for the question “Is the Package useful for you? Why?”
    - Yes, extremely useful. The exercises presented in this way are interesting, they provide the opportunity to solve tasks with a different approach. This is the way students prefer learning, and feedback which makes exercises even more relevant.
    - I don’t like computer games
    - Yes. The exercises are presented in an accessible and understandable language for the respective pupils' age.
    - Solving tasks step by step leads to a faster resolution of the problem. Showing possible mistakes in exercises is a good approach to learning.
    - Yes. Exercises, presented this way, become easy to perform, showing opportunities to solve various problems. Type 3 is suitable for training because it enables the teacher to show the possible mistakes that are allowed in solving a particular task.
    - Solving tasks step by step leads to a faster resolution of the problem. Showing possible mistakes in exercises is a good approach to learning.
    - Yes. Exercises are easy to implement, they can solve specific problems. Different, interesting and new way to solve tasks.
    - My students enjoyed working with the project as well as I did. The tasks were in the approximate level of difficulty and did not feel to overwhelming. The user interface is easy to use as well.

Most of the teachers recognize that the apps are good but probably they could be improved upon, and that the creation of the exercises is clear and easy.

4.4. Survey feedbacks in details and deduction

Students

The “DWS - Student questionnaire” survey [1], requested to fill in for free, shows:

- By students from 15 to 19 years old:
    - 205 of them have done between 1-5 exercises
    - 50 students from 6 to 10
    - 40 students have done over 10 exercises;
- By subjects:
    - Mathematics 120 exercises were done, 41 per cent of respondents
    - Physics 75 exercises are done, 25% of respondents
    - Science 100 exercises, 34% of respondents.
    - Answering the question “Which app did you use?
    - 219 students preferred to use Android
    - 47 students preferred to use the web portal
    - 29 of the students surveyed preferred to use IOS

- Answering to the question "The app was?"
  - 72% of all 295 students gave very good ratings (150 students) and good (60 students).
  - 11% are not satisfied and answered with bad
  - 17% gave no bad ratings
- Answering to the question "Comments and/or questions"
    - Students' comments are mostly related to the location of exercises. Sometimes it is difficult for them to find the right type of exercise and its place. They couldn't find quickly the exercises in interest. Many of those who took part in the study, have come to believe that this learning is useful, interesting and preferable to the standard one.
    - Some very interesting comments and/or questions were:
    - Why having islands when you can have well organised menus?
    - I think the biggest problem comes from the translation of some of the exercises
- Maybe there need to be a better GUI
    - Very nice, very good, nice work, perfectly sufficient
    - The App is very useful!
    - Good job. Perfect! Nice!

Teachers

The "DWS - Teacher questionnaire" survey [3], requested to fill in for free, shows:

- Answering to the question "What aspects of the web portals were most useful or valuable?"
  - The portal is very valuable concerning the three typologies;
  - It isn't allowed to change from one ex to another one without coming to the end.
  - Sometimes, with IOS, at the middle of type 2, it pushes me out of the ex. Chosen English, if we search for specific ex, the list of proposed exercises isn't complete and sometimes it appears in Italian.
  - The graphical interface is very simple and intuitive.
  - The portal seems very suitable for collective use in the classroom (in my case using the video projector). The unconventional situation allowed me to involve students in a more playful, relaxed and collective approach to problem solving. The need to look for different exercises for students and the possibility of navigating among many themes allowed me to refresh even "old" subjects and to evaluate their permanence. It is very gratifying for students to be able to solve exercises on subjects they haven't seen for a long time. The difference in approach and language with respect to those who formulated problems, sometimes makes the interpretation of the answers difficult, but forces a useful exercise of adaptation and elasticity.
  - Easy access.
  - The idea seems good: it could be interesting to have some exercises on which students can practice with the "methodology" proposed in DWS.

  - In many exercises errors (even rough ones) are found: this makes the instrument unreliable. The best result that can be achieved is to have students try to find and correct errors in the proposed exercises
  - The students tell me that when using the app different things are seen on android vs iOs
  - The structure of the exercises is not very intuitive
  - Often English is also questionable
  - I had intention of inserting exercises, but I didn't find a way to do it
  - In the questionnaire that the teachers must complete at the end, the questions relating to the creation of exercises are mandatory, although it is not mandatory to have entered exercises
  - In the evaluation of portal and app, 3 items out of 4 are positive (very good / good / not bad) while one is negative (bad): this clearly pushes respondents to focus on “not bad” even in case of judgment not positive on the project, clearly distorting the results of the questionnaire
  - The graphics are ugly (subjective judgment, therefore questionable)
  - The topics (the names of the villages within the islands) are not readable
  - I often disagree with "what is the best strategy" to solve a problem
  - The layout of the mathematical formulas is ugly (subjective judgment, therefore questionable)
  - The structuring of the exercises in the three types, above all the one that also proposes incorrect alternatives.
  - Graphic: islands, villages
- Answering to the question “What aspects of the App were most useful or valuable?”
  - The app could be very interesting for the students, with the possibility to use at any moment of the day, also in class if the teacher agrees.
  - The possibility of proposing exercises in different ways than using a text. I have not prepared or entered any exercise
  - In the islands, the cities sometimes develop too wide arguments and therefore it is difficult to find, in a fast way, exercises related to the topic you want to play.
  - The interface is similar to a game, and therefore closer to young people's learning methods. In the initial phase (time permitting) it would also be useful to develop these paths with the children, taking advantage of the project to analyse in depth an algorithm or a concept. Unfortunately, at this stage of the year it was not possible, but the idea is very interesting and intrigued the students.
  - The tool was used a lot by young people, the game-like interface intrigued the kids and caught their attention. It would be interesting to have time to learn more about this app with the kids
  - The graphical interface is very simple and intuitive
  - The applets is definitely closer to the spirit of many kids (especially the younger ones) and the idea of being able to use mobile phones for schooling has had an effect of involvement and has produced curiosity. I don't know how much the

"novelty" effect counts and how long the initial interest is going to last. However, several students have used the app, even alone at home.

  - Graphic: islands, villages

- Answering to the question "How would you improve DWS web portal or apps?"
  - Addition of virtual labs, use as a tool for flipping classroom.
  - It is too slow.
  - Making the answers more understandable and adjusting the languages
  - The titles of the series of exercises are too general and force the user to open the exercise to discover, perhaps, that they do not yet know how to deal with it. Example: in the Algebra - algebraic expressions section, it is not specified if they are integer or fractional. It would be nice to improve the structure of the "islands" inside each subject. I find a lot of overlap among the subjects (e.g. functions and analysis, mechanics and dynamics). A clearer structure and less overlapping among different "chapters" or "areas" (maybe not totally avoidable) would be useful to help students find exercises on the topics they need.
  - Maybe an indication of the level of difficulty a student could expect from an exercise would be useful, to go along with the topic of the exercise.
  - I found the app on Android kind of slow. The web portal was a better experience in my opinion.
  - The portal could be more interactive and more user-friendly. The challenge among the students should be developed.
  - Delete the explorer part of the exercises. These often confuse the students.
  - The interactivity and the creation of multiple-choice paths, with the explanation on the possible mistakes made, or the comment on the correct choices but still more or less elegant.
  - The possibility of greater interaction between the proposed exercise and the students. Some comments or explanations on the various steps.
  - The navigator version is often very boring because obviously it is not interactive. Some exercises also in the other two versions do not have multiple answers and do not entertain the students who see the possibility of making a mistake denied (playful component).
  - Certainly, already planned operations of setting up the platform (more reliable software, development of other language versions, revision of the exercises also in the linguistic formulation, etc.) should be completed. A greater number of exercises would be required for the platform to be used over time. It would be interesting to know the geographical origin of the businesses (as was initially announced in the meetings). It might be interesting to introduce the possibility of using a random exercise generator (for defined categories) instead of leaving the choice only to the user, thus enhancing the emotional component.
  - I don't know.
  - Improve the clarity of the portal and the speed of response of the system: navigation is difficult and too slow. More useful and the graphic more clear and visible.

- More user-friendly to insert images and formulas
- Creating form to search the exercise by name of the teacher, name of the exercise, number of the exercise, etc.
- Creating tab to search an exercise easiest.
- Sometimes the app or portal are very slow.
- The home page of the portal is not very user-friendly.
- Type 3 is suitable for training because it enables the teacher to show the possible mistakes that are allowed in solving a particular task
- Extremely useful
- My students enjoyed working with the project as well as I did
- The user interface is easy to use as well.
- Deduction
- Reading the surveys of the students and recalling that the survey was not compulsory, it could summarize that the students have dealt with the Maths exercises first, then those of Natural Sciences and finally those of Physics. Also, the surveys seem to indicate that the students prefer using the mobile device instead of the pc or laptop and to give the information that “Do Well Science” is on the right track, but could be improved. Reading the comments, it could be found that most of them wrote that the project idea is excellent and also the exercises. In some case the students ask to fix the bugs in the app concerning the score, some symbols, the English translation. They paid a lot of attention to the system that offers them the exercises and they know that the enhancement could be done. The students greatly appreciated the presentation and development methodology of the exercises.
- The exercises presented in this way are interesting, the students are provided the opportunity to solve tasks with a different approach. This could be the way that students prefer learning and feedback, which makes exercises even more relevant. The exercises served in this way become easy to execute, showing opportunities to solve various problems.

By reading the surveys of teachers and students, it could be concluded that the below comparative analysis of the main common trends and most relevant differences emerged between the traditional learning methods and the learning process based on the “Do well Science” e-platform:

- despite the popularity of online education, vast groups of students consciously stay away from such methods, mostly due to misconception;
- at the same time, despite the rising popularity of using the brilliant option of the island as a means to a specific scientific area, traditional (classroom) training is fighting back and trying to adopt newer means of retaining learners' interest, such as the experiments in the lab, especially for the Natural Sciences courses;
- digital classroom learning helps students and teachers know each other in a better manner. Increasing students’ participation in their own learning has been a goal of educators, no matter the specific scientific field, for a considerable time. This

allows teachers to know the students and to better evaluate their strengths and weaknesses, act as mentors, and guide students in their career possibilities.

Summarizing the answers, there are always two sides of a coin: for some individuals digital training is more appropriate, but for others traditional-classroom training is the preferred delivery method. Then, teachers found the exercises useful and necessary didactic tool in the interactive way of learning and student could learn in a different and more useful mode.

4.5. Problems and challenges of the content creator

The procedure for creating an exercise by teachers is a long work. In addition to some technical difficulties due to the way the exercise is inserted, but which are quickly acquired through practice, teachers need to concentrate on the development of the exercise, seeking a new solution vision that is appropriate for their class and sometimes for a single person or a group of students. Specifically, the development of an exercise procedure includes different skills of teachers in terms of: identifying the type of exercise as an aid to their class, identifying the difficulty of the exercise, creating an interesting and easy-to-follow path for the students, develop the exercise without too many approximations and without going too far in the explanations, identifying the points of interest, inserting in the exercise "common" difficulties of their students, highlighting the most suitable solution strategies, stimulating students with the assignment of score.

At the centre of attention must be the student but it is the teacher who must make him participate and interested through the new way of presenting the "Do Well Science" project.

Bulgaria

Developing the three types of exercises was a challenge for the teachers at SPGE “J. Atanasov”. Each of them chose several of the suggested exercises that are the closest to what he/she does with the students and what he/she will be able to present in the best way to reach the project goals. The implementation of the exercises of types 1 and 2, where the exercises describe the options that can lead to the solution of a problem or task, allow the development of the pedagogical abilities of the teachers of our high school.

The teachers encountered the most difficulties in developing the third type of exercises where the kind of errors had to be shown. In this type, the teachers showed their professionalism by analysing all the options where students could make mistakes. Each exercise of this type is a wonderful training tool.

The difficulties in creating exercises were encountered by teachers when writing the individual steps and referring to the next steps. This had to be considered very precisely so that after their development, the exercises could be uploaded on the platform so that inaccuracies could be avoided in the visualization. The work of the Bulgarian team in creating this product was interesting and fruitful.

We received the assurance that the work is well done after the testing with students and their satisfaction from learning.

Teachers and students together showed that learning at school can be easier and interesting.

Greece

The development of the exercises through the "Content Creator" was a very interesting process for the teachers of "Arsakeio".

The selection of the exercises was a challenge for the teachers. The topics were very clear from the beginning of the project and the teachers had to choose exercises suitable for the students in secondary education. The exercises should be relevant to their school books, easy to understand and resolved in two or more different ways. This last part was not easy to achieve for the exercises in Natural Sciences.

Writing exercises in the English language was another challenge for them. Since they don't use this language in teaching, they had to recall to their memory the scientific terminology. Of course, the help of the English teachers was precious.

A serious difficulty that a lot of teachers encountered was writing equations with mathematical symbols. The "Content Creator" environment was not friendly for this process and the teachers had to make a lot of steps and moves until the equation appeared as an image. So, writing exercises for Mathematics and Physics was a time-consuming process.

Writing the exercises in three different types was an interesting and innovative idea. The third type (multiple choice) was the most demanding for the teachers. They had to give a lot of different possible answers and also predict the errors which students make and then comment on these errors to give the feedback. The third type was suitable for exercises in Chemistry and Biology but also was a useful teaching tool for all the teachers to increase the interest and competitiveness of the students in the classroom.

Despite those difficulties, the teachers of "Arsakeio" involved in writing the exercises, enjoyed their participation in the process. They collaborated with teachers from Italy and Bulgaria exchanging thoughts and opinions about common teaching issues and they are waiting for the acceptance of their work.

Italy

The Italian teachers have found the same difficulties as the Bulgarian and Greek colleagues because the implementation of the solutions of the exercises has a slightly different logic from that which they usually carry out in the classroom. The main difference was that of necessarily having to transcribe in the form of a question and answer all those considerations that are usually made in an active discussion in the classroom.

Sweden

The Swedish teachers, since they mainly developed exercises in Biology, implemented the exercises almost exclusively in the Navigator mode, since it was the one most suited to the questions that they usually pose to the student and for which a draft with "Do Well Science" allows a different view that helps students in the skills they need to develop.

4.6. Achievements of the Bulgarian and Greek students

As already mentioned, many students appreciated the “Do Well Science” methodology. Although the project does not foresee that the proposed exercises could be a form of teacher evaluation by the students, some teachers did small tests on some exercises created.

Bulgaria

Students generally demonstrated a quick understanding of how to perform the exercises, an understanding of the text and the requests and a user-friendly app.

Some comments were also very interesting, such as: "so I do first to go over" or "I will need it right these days" or even "it looks just like what we do in class".

Objective results could be analysed only with a real experimentation over time but the premises are more than satisfactory, let alone the appealing graphics of the app and the web portal and the possibility of sharing the achieved score on the social networks.

Teachers, working on the project, and students from SPGE “J. Atanasov” tested the developed exercises. 320 students from 8th to 12th grade participated. These are students aged 14-18.

The testing was done in classes of Mathematics, Physics and Natural Sciences - Biology and Chemistry. The Maths teachers worked mostly with the 11th and 12th grades where the proposed exercises were appropriate for revision and recycling of background knowledge. Students from 9th and 10th grades took part in the Biology and Chemistry exercises. The material proposed in the exercises covered the curricular content of these classes.

All students at different ages from SPGE were included in doing the exercises in Physics. First, the exercises were done with the 12th grade students who were preparing themselves for a state matriculation exam in Physics. In this way, they revised the basic concepts, laws and formulas necessary for their preparation.

The eighth graders were then included, with the curriculum content of mechanics and fluid mechanics. In the exercises concerning energy and energy conservation laws, as well as impulse preservation law, students from the 10th and the 11th grade studying Physics as a compulsory or optional subject took part.

The students did the testing with interest and we are now preparing exercises in Bulgarian language so that they can be easily understood by all.

Greece

About 100 students of all the classes of “Arsakeio” Lyceum were involved in testing the exercises. The teachers participating in the program informed the students of how the application works and how the exercises are processed. The testing phase took place in the classrooms during the lessons in Mathematics, Physics, Chemistry and Biology and also some of the students worked on their own at home. At first, students were reluctant to be involved due to some technical difficulties concerning the web portal and the App, as well as the fact that the exercises were not written in their mother tongue. In the following weeks, however, the students became more familiar with the philosophy of the exercises. It is very important to mention that the third type of the exercises was more appealing to the students. This could be attributed to the fact that they had the chance to work in groups and their competitive spirit was challenged.

The results were particularly encouraging as students found the application useful and a different way of approaching Natural Sciences and Mathematics. They argued that the application could be an additional tool in the educational process and a knowledge check on what they have been taught. Additionally, the application could be used for the final revision before the exam. A further reason that students showed interest in the application is the use of new technologies.

In conclusion, the “Do Well Science” web portal and the App offered a flexible, efficient and interesting learning tool to the majority of the students.

4.7. A brief indication from partners

Bulgaria

The use of the exercises in the teachers’ and students’ work will create a close and friendly atmosphere and will enable them to jointly solve problems and tasks. Students will learn from their mistakes and will have the opportunity to choose the way they can solve a task or a problem.

The inquired teachers find that working in this way is a wonderful didactic tool in the context of modern technology.

Using a phone app is a good way to get accurate and true information quickly and at any time. The students did the exercise test through both their PCs and their phones and in the two cases the results were the same.

The training thus corresponds to the mathematical competence, the basic competences in the field of Natural Sciences, the technologies and the key digital competence, in accordance with Article 2, paragraph 1 of Ordinance 5 from 30.11.2015 for general education, issued by the Ministry of Education and Science.

Subjects such as Mathematics, Physics and Natural Sciences are directly related to the acquisition of mathematical competence and basic competences in the field of Natural Sciences and aim at achieving mathematical and scientific literacy. Along with these competences, students develop skills for critical thinking, problem solving, decision making and initiative.

Greece

The implementation of innovative technology in the teaching and learning process is the basic tool in serving the objectives of the Greek educational system. Thus, new methodologies that cultivate experiential and cooperative learning are promoted. Also, the Greek educational system motivates the educator to make use of the possibilities offered by the constant evolution of digital technology to facilitate and upgrade the quality of its work, www.minedu.gov.gr.

In Greece, Digital educational content for primary and secondary education is a key pillar of digital national policy for the incorporation and constructive utilization of Information & Communication Technologies, ICT, in school education, www.dschool.edu.gr. The creation of digital Open Educational Resources, development Digital repositories for the organization, search and wide availability of educational resources in the school community, as well as the development of a digital educational platform for pupils and students educational and pedagogical frameworks for their use in the learning process are the central objective of the Greek Ministry of Education, Research and Religious Affairs actions on Digital Educational Content.

According to the "Do Well Science" Project results, this project not only helps students to reflect on the process of solving problems, acquire skills and strengthen their critical thinking but also offers the teachers the ability to turn the traditional lesson into a more modern lesson, tailored to the demands and needs of the era. In conclusion, "Do Well Science" Project constitutes an innovative pedagogical-teaching method through which the Greek educational objectives are being served.

Italy

In Italy there is a progressive revision of the teaching methods of schools of all levels, to increasingly integrate scientific subjects, STEM, with other disciplinary fields.

The study activities aim at identifying effective strategies, solutions, models and approaches for the management of learning processes, taking into account the variety of contributions coming from different research approaches: cognitive psychology, neuroscience, social psychology, anthropology, pedagogy, and the need to make explicit the scientific competences that are to be promoted.

Moreover, this research path intends to enhance all those activities that focus on the collaboration between researchers and teachers in real learning contexts, which thus become real "laboratories" for research. "Do Well Science" is a good practice of collaboration among schools of same and different grades, and a possible mean for students to improve their skills from how their teachers like to teach.

"Do Well Science" is an opportunity to help the school system improve the STEM disciplines using the ICT as an easy and effective approach, because it is addressed directly at the students of the teachers who would engage in the creation of the exercises.

4.8. References

[1] “DWS - Student questionnaire.pdf”, appendix 3

[2] “DWS - Exercise suggestion.pdf”, appendix 4

[3] “DWS - Teacher questionnaire.pdf”, appendix 5

[4] “DWS – Project Evaluation by end users.doc”, appendix 6

PART III

Teaching STEM with ICT: why?

1. Research on innovative approaches to the teaching of STEM and their adaptability to the particular educational process in the different secondary level schools

by Petros Karkoulias, Miglena Molhova-Vladova, Gianluca Olcese

1.1. Introduction

The contents of this chapter deal with the issue of combining both technical and methodological approachs by illustrating the main theoretical findings that emerged during the project. These contents are also a practical guide to teachers based on the best practice in using alternative pathways to teaching STEM based on enquiry, centred on student and on argumentation group discussions.

The key strategy is to engage or re-engage children and youth in Science and Mathematics in ways that are authentic, interesting and meaningful for the learners themselves. The system currently is struggling in this regard today: the curriculum and its assessment are dull, encourage teaching narrowly to low - level fact - based tests, fail to encourage creativity, and switch the majority of learners off. This module touches on the sensitive issues of how innovation can be implemented in STEM education and what are the main questions which must be regarded by school administrations and teachers in secondary schools.

1.2. Innovative approaches for the teaching of STEM

When we discuss innovative approaches in teaching STEM, we first must consider some basic factors that teachers have to take into account for innovations in teaching STEM to happen. Such factors come from the various studies, which investigating results of students in STEM education, focus not only on the teaching methods, but also on the models of learning and remembering information of students. More and more studies focus on the cognitive model of thinking and understanding of students; on child-instigated approaches in teaching rather than teacher-instigated ones. Furthermore, the constructivist theory teaches us that children build their knowledge on previous experiences. There are also other theories regarding learning in general and learning of STEM in particular, but all of them focus on 3 main points:

- Children construct their own understanding;
- Learning is enhanced through social interaction;
- The educator is pivotal to children's learning. [1]

Also, according to Campbell and Chealuck, the approaches for enhancing science learning can be grouped as follows:

- Intentional thinking, the term 'intentional teaching' has been used to describe the deliberate decisions and actions of an educator in the way they approach children's learning. However, intentional teaching is not a 'formal' teaching approach and is not intended to mimic a school structured approach: rather, it is recognized as educators enhancing children's learning through play in a purposeful way.

- Science as developing a sense of understanding of the world, children need exposure to new experiences, new materials and the opportunities to explore new ideas. This exposure provides them with the basis for constructing meaning.
- Process skill approach, in the process skills approach, the educator assists children in developing Science skills. While building Science knowledge, we also want children to develop the skills and processes to be able to confidently undertake their own investigations. In the process skills approach the educator focuses on a particular scientific skill, such as observing or communicating, or some combination of process skills.
- Guided discovery approach, children attempt to make sense of their world through their own play explorations and, if a constructivist approach to learning is accepted, children build their own understandings from their own experiences. However, children are limited in how far the discovery can aid understanding. Interaction with peers and adults provides additional stimulus to extend understanding further.
- Interactive approach and inquiry learning approach, the interactive approach to learning recognises that children have legitimate questions of their own to which they would like to find answers. In this approach, the children's questions lead the explorations and the educator's role is to provide resources and guide/scaffold the explorations. The educator supports the development of the children's ideas, asks focused questions, suggests alternative ways of thinking and helps develop children's responses.
- Problem-based learning approach, where the educator provides a problem to children, usually in small groups, and gives them time to try to solve it. It is a child-centred approach.
- Project approach,where children are involved collaboratively in a particular project that requires problem-solving around a specific need.

Innovations in teaching and learning Science in the recent years are focused on technology-assisted education process and creativity enhanced approach, urging students to generate new ideas. The technology enhanced educational approaches are associated with gaming, virtual laboratories, international collaborative projects, real-time formative assessment and skills-based assessment. More about the technology enhanced pedagogical approaches you can read in the previous Chapters.

Here we will pay more attention to the necessity to enhance creativity in students during Science teaching and learning and the trend to add A in STEM, which stands for art.

There are five types of nurturing creative learning activities in Science which are:

- discovery;
- understanding;
- presentation;
- application;
- transformation of scientific knowledge.

To get creativity through discovery activities, teachers can ask students to do independent research activities, or involve in divergent thinking training of students in Science process skills. Students are encouraged to develop Science; it is an interesting and diverse range of scientific observation, to do classification, ask questions of scientific research, form hypotheses, plan trial and methods of measurement, use equipment or appliances, and make conclusions from empirical data. [2]

Linking the understanding of creativity with Science teaching can help teachers wor in a better way with students, on the one hand improving students’ creativity and on the other, to assess how much of the scientific material taught is really understood by students. Connecting levels of comprehension and levels of creativity can help teachers measure both, since they are interrelated: a higher level of creativity shows higher level of comprehension and vice versa; linking levels of comprehension and creativity can also help teachers understand more about the prior knowledge the students have access to and also about the cultural background and context of this knowledge.

A summary of the levels of creativity, with which teachers can estimate how much of the prior knowledge the student actually uses and how much of the scientific concepts he understands, because the higher the creativity he/she shows, the better understanding of the material stands behind it.

<u>Level of creativity</u> [3]

Explanation.

Imitation, creation of an identical cue; the basic skill-the starting point for more creative tasks.

Variation, variations of some definite part(s) of the work, the rest is presented identically.

Combination, combination of 2 or more works in one new work.

Transformation, transformation of the existing work into another form or the way of presentation.

Original work, creation of a new original work that has a slight resemblance or no connection with the previous work.

Integrating arts in Science can help students learn how to express ideas and emotions by performing. Adding drama pedagogical tools in Science classes will require for students to analyse critically a specific problem, to reflect on it so that it is expressed on the one hand with a scientifically correct way and on the other with different pedagogical means than the widely known ones. Arts education trains students in complex thinking and encourages a path of thinking that often leads to innovative solutions or even multiple solutions, as when an actor tries different ways of portraying a character.

A summary of innovative teaching approaches in STEM and strategies for these approaches to be put in practice in class can be found here: www.edsys.in/innovative-science-teaching-methods/. Additional resources on the paragraph topic can be found in [4][5][6][7][8].

1.3. How to evaluate the adaptability and transferability of an innovative approach for teaching of STEM in the educational process in school

One of the first points to consider in innovation implementation in STEM education is what is understood under "innovation" in this context. Each school is free to set its own definition and criteria to put behind this concept, so that it is understood and accepted by the academic community that works in the school. Obviously, there is always the possibility to choose a formal definition, by recognized academics in the field or organizations working on this topic, who have investigated number of practices.

Here we can give one such definition of the OECD, which specifically put efforts in measuring innovation in education:

"The implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations."

Educational organizations, schools, universities, training centres, education publishers, etc., can introduce:

- new products and services, such as new syllabi, textbooks or educational resources;
- new processes for delivering their services, such as e-learning services;
- new ways of organizing their activities, for example communicating with students and parents through digital technologies;
- new marketing techniques, such as differential pricing of postgraduate courses.

Such new practices aim at improving the provision of education in one way or another, and should therefore be regarded as intended "improvements" [9].

Since innovation is about change, it is important how we measure that change in the school practice. In this process school administration must first identify what is considered "traditional" approach in the educational practice and then see what is changed and how big this change is.

Criteria that can be determined with this regard could be:

- the <u>curriculum</u> being targeted, e.g. its intensity, structure, size, approach, content, learning processes, instructional materials, curriculum 'fit' and so on;
- the <u>teaching</u> being targeted, e.g. staff numbers, qualifications, familiarity with methodology, status of staff, contextual factors impacting on teaching such as funding and so on;
- the <u>learning</u> being targeted, e.g. student selection process, language background, previous education, academic achievement, contextual factors impacting on learning such as time-tabling and so on [10].

INNOVATION

Some specific criteria that can be used to determine the change in traditional and innovative educational approaches could be:

INNOVATION IN THE CLASSROOM - PEDAGOGICAL PRACTICES

- possibility for students to design their own experiments;
- scope for students to explain their ideas;
- explain the relevance of Science in everyday life;
- use of memorization of facts and procedures as a pedagogical technique;
- using computer simulations for learning;
- using computers to practice skills and procedures.

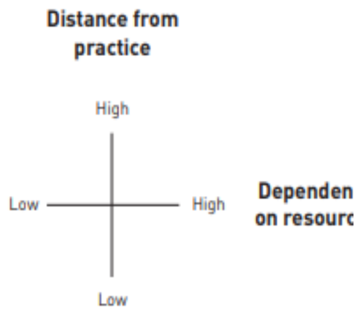
INNOVATION IN SCHOOLS - WORK PRACTICES AND RESOURCES

- teacher collaboration in form of peer observation;
- teacher collaboration through teaching discussion with peers;
- professional development for fostering students’ critical thinking and problem solving;
- availability of laptops or notebooks in schools.

INNOVATION IN EXTERNAL RELATIONS

- parental involvement in school activities;
- public posting of school achievement data.

At the core of successful innovation in schools is the relationship among the innovation, the capacity and disposition of the innovator, and the environment in which the innovation occurs [3].



Zhao et al. (2002) argues that a two-axis scale can be used to understand the potential success of an innovation through the capacity of an organization or individual to engage with change. On the vertical axis is the distance of the innovation from the existing practice. They suggest that the closer the innovation is to existing practice, the easier it will be to adopt. Here practice can relate to classroom practice, pedagogy, school culture or structures within the school depending on the nature of the innovation. Indeed, the definition of the ‘change to practice’ is a context bound by those who use this model. The horizontal axis shows the degree to which the innovation is dependent on resources for success. This relates to the resources needed for the innovation and the extent to which they differ from existing school resources. Resources can be a broad category including technical resources such as equipment or web access, human resources such as extra staff to support activities and planning time, or physical resources such as classroom space. The less demand the innovation puts on extra school resource levels the more likely it is to succeed [11]. Additional resources on the paragraph topic can be found in [12][13][14][15].

1.4. Creating innovative learning environments

Innovation in education has never been an easy task and the school systems are some of the most conservative ones and usually governed publicly, which makes changes slow and top-down driven, which is not always the best way for a change to happen. Building innovative learning environments for STEM requires step by step approach. As a first stage the school administration may consider doing old things in new ways, using interactive white boards to represent content instead of the classic boards is one example. As a second stage, school may focus on new ways of teaching and learning, adopting new pedagogical approaches, strategies and tools. Of course, this cannot happen at the same time for the entire school and for all teachers; the school must work on building a critical mass of "teacher-innovators" who can be the leaders of change for their colleagues. This is necessary also to reach the stage three of implementing innovation. Generally speaking building an innovative learning environment will require the development of a school innovation strategy to acknowledge a shift in thinking about education, a shift that advocates moving away from: a teacher-centred classroom to a learning-centred classroom, from a system that relies on single sense stimulation to a system that enables multiple intelligences, from a single media environment to a multimedia environment, from isolated work to collaborative work, from isolated artificial content to authentic real world experiences, and from information delivery to information exchange.

Learning principles

To be the most effective, schools and other learning environments should attend to all of the following design principles:

- Learning Principle One: make learning central, encourage engagement, and be where learners come to understand themselves as learners.
- Learning Principle Two: ensure that learning is social and often collaborative.
- Learning Principle Three: be highly attuned to learners' motivations and the importance of emotions.
- Learning Principle Four: be acutely sensitive to individual differences including in prior knowledge.
- Learning Principle Five: be demanding for each learner but without excessive overload.
- Learning Principle Six: use assessments consistent with these aims, with strong emphasis on formative feedback.
- Learning Principle Seven: promote horizontal connectedness across learning activities and subjects, in- and out-of-school [16].

Additional resources on the paragraph topic can be found in [17][18][19][20][21].

1.5. Language as a key factor

The romance philologist Michail Bachtin stated that: “The exact science is a monological form of knowledge: the mind contemplates a thing, on which pronunciation is performed; here there is only a subject: he who knows (contemplates) and speaks (pronounces). In front of him there is only the dumb thing” [22]. It means that the human sciences are sciences that study man in his specificity, and not the dumb thing and the natural phenomenon. Human being in his specificity always expresses himself (speaks), that is, he creates a text (albeit potential).

This is a phenomenon of enormous importance ,which scientific teachers must be aware of. In fact, on the one hand it is obvious that it is not enough to know a language to read a scientific treatise in that language; one thing is the learning of the fundamental, grammatical and lexical structures of a language and completely different is what is technically called the 'microlanguage', i.e. the language of specialization in a given science, which certainly presupposes the general study of that language , but also the specific study of that scientific language, of its forms and its contents and therefore a theoretical definition of this specific code, its structures, its semantisms, its working mechanisms. But it is also true, on the other hand, that microlanguage is the tool that is used in the teaching of science that is taught to gradually lead students to the knowledge of its conceptual cornerstones.

The teaching process, as it is implemented today, is very often a one-way communication that goes from the teacher to the student, interrupted only by oral tests or by written tests. Instead, the relationship between teacher and student must also take place when the teacher explains the lesson. This relationship means that either the teacher or the student, must initially find a common language on which to converge, since it is certain that, at the outset, the forms of communication are clearly unequal. This means having to search for an undoubtedly difficult balance between properly individual forms of communication-expression and a common code on which to converge.

The symbols, which are the real "written language" of chemists, are probably the most emblematic example of a polysynthetic language, and this can be grasped the more the chemical is known; from this point of view it would be fundamental to let the students focus on how the meaning of the formulas for them is getting richer and richer the more the learning of Chemistry proceeds. For chemists, the formulas are an indispensable intellectual and operational tool, but for the students, whether they do not yet know the structure and the logical and historical development of Chemistry, what can the latter mean?

The language of Science is the sectorial language of which the texts produced in the field of scientific research are typically constituted and spread. These are the texts in which the following conditions are fulfilled: the subject of the text is exclusively the objective reality and whatever subjective intrusion by the author is banned; at the centre of the relationship between the text and the extra-textual reality is the principle of verifiability or falsifiability of the statements produced; the text must be decoded on the basis of standardized codes, therefore it should keep strong constraints on interpretation.

For Michail Bachtin: “The objective unity of cognition knows no ending as something which possesses positive validity: it is not Science that begins and ends, but the scientist. The end, the beginning, and a considerable number of the compositional moments of a learned treatise reflect the activity of its author-subiectum, that is, they are aesthetic moments, which do not penetrate into the open, infinite, and beginningless world of cognition” [23].

The field of studies (the studied objects themselves) is, however, divided into two great articulations. On the one hand we can consider the studies of (or based on) physical and natural reality: and, in addition to Physics, Chemistry, Biology, etc., we can include in this area the same Mathematics that - even with the maximum of abstraction which it reaches - it is always founded and inscribed in natural reality if we remember, with Galileo, that the universe: “It is written in mathematical language, and the letters are triangles, circles and other geometrical figures, without which means it is humanly impossible to comprehend a single word”.

On the other hand are the studies that concern - rather than ‘things’ - the ‘signs’, which concern mankind (hence the term ‘human sciences’): however, not the human being in itself, but as a producer (or receiver) of signs or, better, of texts.

In reality, each object can be studied with a scientific method, a method defined from time to time within the epistemological status of the various fields of study, but which often assumes as a model, as far as possible, that of the exact and experimental sciences, considered for excellence the ‘scientific disciplines’. The adoption or the tension towards a scientific method justifies for those subjects the term of ‘human sciences’.

Additional resources on the paragraph topic can be found in [24][25][26][27][28].

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2. Technology-enhanced STEM learning

by Petros Karkoulias, Miglena Molhova-Vladova

2.1. Virtual and remote Science laboratories and inquiry learning applets

In recent years, Inquiry-Based Science Education (IBSE) has proved its efficacy in education by expanding on “traditional” lessons and motivating students to actively participate in Science [1]. IBSE methods and digital technologies support necessary educational innovations and can be the catalyst for change in educational patterns (in regard to its form, space, functions, services, tools, roles, procedures) [2]. Virtual laboratories are an essential digital tool. In fact, many European schools are equipped with computer classes, tablets and high-speed internet connection while using a huge variety of web-based learning applications, simulations and visualizations [3].

Description of virtual laboratories environments

Virtual laboratory environments can be divided into the following categories [4]:

Simulations

Simulations are imitations of operating systems through time, via computers. These represent a process on the basis of a model that is cheaper, faster, less risky and more affordable than the real process.

Network applets

The applets are experimental devices in small virtual laboratories and are quite popular in Science subjects. They are small in size and easily transported and they can be used regardless of the operating system type.

Virtual labs

Virtual labs (virtual laboratories) simulate a virtual operating system, the computer screen, Science laboratories, exploiting the potential offered by modern media technology, key feature technical interaction and direct and plausible manipulation of objects and parameters.

Virtual Reality Laboratories (VRL)

VRL workshops are computer based and highly interactive. The user becomes a participant in a “virtually real” world, in an artificial three-dimensional optical environment. These workshops are essentially an high level interface including real time three-dimensional simulations through different sensory channels.

Laboratories Controlled by Distance (Remote Labs)

Workshops controlled remotely (remote labs, otherwise known as online labs or workbenches) include real experiments conducted from a distance with the use of telecommunications, while the user uses this technology from another location.

Most of the virtual laboratory software consists on computing applications running on the local user’s computer, for speed and security reasons. They can be operated remotely. An example is those based on applets or robotic workshops (remote labs) that can accept commands via the Internet [5].

Benefits of using virtual labs in teaching and learning Science [6]

Virtual labs can be very useful in the teaching of Science, particularly in cases where the experimental activities are to be done quickly and do not easily allow observation and safe measurement, the experimental process is very slow and/ or complex and not compatible with the teaching time available, the experiments involve risks to the health and physical integrity of learners and/or the learning activities require modelling.

Virtual labs support IBSL in learning Science:

- laws in Science arise from a detailed observation process, with clearly more chances of clarification, understanding and acceptance if regarded in detail;
- it encourages collaboration and communication between teachers and students. STEM teachers participate actively in the learning process: asking questions, trying to find answers, organizing procedures and commenting on them, helping in formulating conclusions, understanding their mistakes and highlighting any misconceptions.

But what are the differences between real life experiences and those formed by representations in a computer screen?

With virtual labs, students acquire a tool with which to experiment without limitations of space or time. They are available all year, as opposed to school laboratories, limited to a specific place and for a limited time [7].

The use of virtual environments makes students acquire better computer skills, which can be considered skills for lifelong learning. The use of these technologies also brings together different STEM subjects and provides with great resources for more inclusive workshops [8][9].

2.2. Gamification of learning

Gamification of learning is an interactive educational approach that motivates students to learn by using video game design and game elements in learning environments [10][11]. The goal is to maximize fun and engagement through capturing the interest of learners and inspiring them to continue learning [12]. Gamification is considered as the process of defining the elements which include games that make those games amusing and motivate players to continue participating, and using those same elements in a non-game context to influence behaviour [13]. In other words, gamification is the introduction of game elements in a non-game situation.

There are two forms of gamification, structural with no subject matter changes, and the altered content method that adds subject matter [14]. Games used in learning can be considered as serious games, where the learning experience is centred around serious stories. The serious story is "impressive in quality" and "part of a thoughtful process" to achieve learning goals [15].

In educational contexts, examples of desired student behaviour which gamification can potentially effect include attending class, focusing on meaningful learning tasks, and taking initiative [16].

Several researchers compare gamification of learning with game-based learning, arguing that gamification occurs only when learning happens in a non-game context, such as a school classroom, and when a series of game elements is arranged into a system or "game layer" which operates in coordination with the learning in that regular classroom [17]. Others include games that are produced to encourage learning [18][19][20].

Gamification activities in learning contexts acknowledge that large numbers of school-aged children play video games, which shapes their identity as people and as learners [21][22][23]. While the world of gaming used to be skewed heavily toward male players, recent statistics show that slightly more than half of videogame players are male: in the United States, 59% male, 41% female, and 52% male, 48% female in Canada [24][25]. Within games and other digital media, students experience opportunities for autonomy, competence and relatedness [26], and these are what they have come to expect from such environments. Offering these same opportunities in the classroom environment is a way to acknowledge students' reality, and to acknowledge that this reality affects who they are as learners [27][28][29][30]. Including elements from games into classroom scenarios is a way to provide students with opportunities to act autonomously, to display competence, and to learn in relationship to others [26]. Game features are a common language that children speak, and an additional channel through which teachers can communicate with their students.

Jane McGonigal, a famous game designer, typifies video game players as serious optimists who are part of a social fabric, involved in great productivity [31]. If teachers can successfully organize their classrooms and curriculum activities to incorporate the elements of games which facilitate such confidence, purpose and integrated sense of mission, students may become immersed in learning and collaborating such that they do not want to stop. The dynamic combination of intrinsic and extrinsic motivators is a powerful force [26] which, if educational contexts can adapt from video games, may increase student motivation, and student learning.

Some of the prospective benefits of successful gamification proposals in the classroom incorporate:

- giving students ownership of their learning [32];
- opportunities for identity work through taking on alternate selves [33];
- freedom to fail and try again without negative repercussions [32];
- chances to increase fun and joy in the classroom [34];
- opportunities for differentiated instruction [34];
- making learning visible [34];

- providing a manageable set of subtasks and tasks;
- inspiring students to discover intrinsic motivators for learning [35];
- motivating students with dyslexia with low levels of motivation [36].

Referring to how video games provide increasingly difficult challenges to players, game designer Amy Jo Kim has suggested that every educational scenario could be set up to operate this way [37]. This game mechanic which involves tracking players' learning in the game, and responding by raising the difficulty level of tasks at just the right moment, keeps players from becoming unnecessarily frustrated with tasks that are too difficult, as well as keeps players from becoming bored with tasks that are too easy. This managing encourages continued engagement and interest which can mean that learners are dedicated on educational tasks, and may get into a state of flow, or deeply absorbed in learning [38].

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3. STEM teacher training

by Petros Karkoulias, Miglena Molhova-Vladova

3.1. Necessity of STEM teacher training at school level

To make innovations integration in the STEM education process, successful school administrators must consider teacher professional development as one of the key factors. Despite the potential benefits of innovations in STEM education, implementation of changes faces several challenges one of the most serious of which is the knowledge that Science teachers own. To effectively implement STEM education innovations, teachers must have deep knowledge of the Science, Technology, Engineering and Mathematics content that they teach, but additionally to that, they must also have specialized knowledge of how to teach STEM content to students, for example pedagogical knowledge [1].

Different studies show that teachers feel underprepared to use STEM applications with their students in the classroom or that teachers do not have sufficient understanding of the T in STEM and that they may not have an adequate understanding of the nature of Science and Technology and the interactions between these two disciplines. Additionally, teachers' beliefs and views about teaching and learning, and their resistance or lack of motivation to change their beliefs and practice, may pose another challenge to the implementation of innovative STEM education.

The majority of STEM teachers surveyed, for example by the European Schoolnet [2], have not taken any ICT-related professional development or training related to innovative STEM teaching in the last two years. When they do follow training, teachers tend to update their knowledge online and in their own time. In terms of supporting groups, most teachers rely on their colleagues of the same subject for updating their knowledge. In general, there is collaboration among teachers in the classroom (38% of STEM teachers surveyed report having received little or no support, even from their colleagues of the same discipline) [2].

There is still a need to educate teachers to teach students in the way that they can work on STEM research, and so that they can design and use the learning environments effectively. Therefore, teacher training programs are really important. The interaction between Science and Maths shows that it is not enough for a teacher to have a teaching knowledge only in their major to raise labour force that our country needs. The studies that analyses teachers' use of similar fields to their major field reveal that there is still a problem with that. For example, pre-service teachers who studied Physics are not satisfactory at Maths, and Maths teachers cannot use Mathematics knowledge while implementing Science experiments. The teachers who will implement STEM education need many courses and workshops which show how to integrate STEM fields while trying to solve real world problems in collaboration.

In this context, Çorlu proposed a model to the researchers that deals with teacher education. The model, which is conceptualized as Integrated Teaching Knowledge, is based on Shulman, Hill, Schilling & Ball and his doctoral dissertation. According to this model, STEM teacher:

- has a professional level content knowledge;
- has a professional level pedagogical content knowledge;
- has the knowledge of another STEM field apart from his/her field of specialization. This knowledge brings competency as a STEM practitioner for field education;
- develops the knowledge related to field by collaborating with the colleagues.

As a result of this collaboration, professional learning communities are formed and collaboration among group teachers is improved. Therefore, major field teacher education programs such as Science, Technology, Engineering (design) and Mathematics teaching should include courses that support integrated teaching knowledge, and there should be professional communication and collaboration opportunities for the teachers from similar fields.

3.2. Development of real-life Science educational scenarios at school and implementation of interdisciplinary approach to STEM education

Great learning occurs when it is participatory, personalised and project/problem-based rather than using a passive input. The past model of education prepared our students for an industrial economy. The future model must prepare our students for a knowledge economy, i.e. an economy in which growth is dependent on the quantity, and on the accessibility of the information available, rather than on the means of production. Invention and problem-solving aren't just for laboratory thinkers hunkered down away from the classroom. Students from elementary to high school can wonder, design, and invent a real product that solves real problems. STEM lessons, which are built around real-life scenarios are an organized, open-ended approach to investigation that promotes creativity. Problem solving is really the heart of STEM investigations. Providing students with real-world problems to solve fuels their curiosity and investigative interests. But identifying real-world problems that students can solve is also one of the hardest parts of creating STEM lessons.

The concept of implementation of an interdisciplinary approach to STEM education is challenging, as integration of subjects is more than a matter of simply putting different subject areas together. The idea of curriculum integration is derived from educators' awareness that real world problems are not separated into isolate disciplines that are taught in schools. In many cases, people need skills that cut across the disciplines. It is important to distinguish the concepts of multidisciplinary and interdisciplinary approach. Overall, multidisciplinary begins and ends with the subject-based content and skills and students are expected to connect the content and skills in different subjects that had been taught in different classrooms. The concepts of interdisciplinary integration are interconnected, in fact they cover different subject areas and focus on interdisciplinary content and skills, rather than subject-based content and skill. Many researchers suggest that an interdisciplinary curriculum is the best form of curriculum integration.

Interdisciplinary curricula start with real world problems or issues. The essential elements that need to be considered in an interdisciplinary curriculum include such skills and knowledge as critical thinking, problem-solving skills, and making connections with learning experiences that relate to personal meanings. If we treat STEM integration as a type of curriculum integration, it manifests its expression; a curricular approach that integrates Science, Technology, Engineering and Mathematics. STEM integration offers students one of the best opportunities to experience learning in a real-world situation, rather than to learn bits and pieces and then to have to assimilate them afterwards. Additionally, Morrison [3] provided the criteria for what an effective STEM instruction should look like in a classroom. She noticed that in a STEM integration class-room, the students should be able:

- to perform as problem-solvers;
- to perform as innovators;
- to perform as inventors;
- to perform as logical thinkers;
- to understand and develop the skills needed for self-reliance;
- to understand and develop technological literacy [1].

3.3. Transnational initiatives for STEM teacher training

Creating a solid STEM foundation through an integrated curriculum is the best way to ensure that students are involved in Science, Technology, Engineering and Maths throughout their educational career. It is also important for educators to have a skill set allowing them to inform students on STEM careers prospects, motivate them and support them.

Professional development of STEM teachers aims at providing them with opportunities to further develop their professional abilities for teaching Science. Current trends in the STEM education and innovation implementation in curricula, interdisciplinary and art approaches integrated in the Science subjects require science teachers to stay tuned with the changes and further develop their pedagogical skills. There are a number of national and international teacher training initiatives which provide access to instructional strategies and practices needed to transform teachers’ classrooms into innovative, engaging STEM environments. Current STEM trainings focus on helping teachers support their students as they put Science and Maths into action through inquiry and problem-based learning process.

Research in teacher professional development (TPD) over the past decade has revealed a number of principles that are important in supporting teacher learning. Generally speaking, TPD can address a variety of teacher needs, focusing on helping teachers refining their teaching approaches and pedagogy, understanding the need to change their everyday practices in particular areas and helping them implementing changes in their daily teaching that will eventually help their students to learn more effectively.

STEM teacher training courses focus on enriching the STEM curriculum through innovative activities for students, on making available learning and teaching resources as well as on enriching educator's skills on engaging and motivating their students. Some courses also explore the need to involve the local community, external experts and scientific organizations.

The resources given to this paragraph show some of the STEM teacher courses available internationally and some of them are also available through Erasmus+ program, which financially makes it easier for willing teachers to participate.

Information about STEM teacher training courses can be found on the links below:

- http://dorea.org/erasmuscourses/promoting-stem-education/
- https://www.discoveryeducation.com/solutions/professional-development/
- https://www.theogtc.com/newsroom/news/2018/innovative-approaches-to-inspiring-stem-in-aberdeen-primary-schools/
- http://www.anatolia-ec.com/erasmus-ka1-courses/21/Innovative-Math-Applications-at-Schools
- https://www.csinfol.it/teacher-training-on-stem-education.html
- https://www.alleducationschools.com/resources/stem-education/

Additional resources

Developing identities of STEM teachers at emerging STEM schools, article, www.ncbi.nlm.nih.gov/pmc/articles/PMC6310437/.

STEM education practices in Europe, http://www.scientix.eu/documents/10137/782005/STEM-Edu-Practices_DEF_WEB.pdf/b4847c2d-2fa8-438c-b080-3793fe26d0c8.

STEM Teacher Education and Professional Development and Training: Challenges and Trends, www.researchgate.net/publication/321097023_STEM_Teacher_Education_and_Professional_Development_and_Training_Challenges_and_Trends.

STEM Projects That Tackle Real-World Problems, education.cu-portland.edu/blog/classroom-resources/real-world-stem-projects/.

Real-World STEM Problems that teachers can address in STEM classes, www.middleweb.com/5003/real-world-stem-problems/.

Practical Applications of Mathematics in Everyday Life, article, owlcation.com/stem/Some-Practical-Applications-of-Mathematics-in-Our-Everyday-Life.

Hands-on activity Solving Everyday Problems Using the Engineering Design Cycle, www.teachengineering.org/activities/view/usu-1961-everyday-problems-introduction-engineering-design.

How to inspire students through real-world inquiry, www.napequity.org/nape-content/uploads/johnson_NAPE-Spark-101-Presentation-Deck.pdf.

Resources for teachers

Solving Real World Problems in the Classroom – A Realistic Application of STEM/STEAM Principles, www.edisonmuckers.org/resources-for-teachers/solving-real-world-problems-in-the-classroom-a-realistic-application-of-stemsteam-principles.

Real-World STEM Tutorial & Software, www.kidwaresoftware.com/real-world-stem-science-technology-engineering-math-tutorial-by-philip-conrod-lou-tylee-kidware-software.

Hacking STEM Lessons & Hands-On Activities: resource with free lesson plans for STEM teachers, www.microsoft.com/en-us/education/education-workshop/default.aspx.

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4. STEM education development strategies

by Petros Karkoulias, Miglena Molhova-Vladova

4.1. Involved and networking communities

Communities play a unique and vital role in the development of equitable and sustainable innovation. Engaging a community and its members in its own future provides fertile ground for new ideas, and the opportunity for broad ownership of the ideas and plans that are adopted. Key community stakeholders do not always serve as public officials, business titans or even community leaders. By identifying a diverse sampling to support and engage in the design process, a community is more likely to have a path of more impactful and sustainable innovations [1].

STEM Networking communities bring educators, business leaders and STEM professionals together to build student success and connect them with STEM career opportunities in their communities. Various involved parts can benefit from this process:

- young people from all backgrounds have the aspiration, knowledge and skills to thrive, with more progressing into STEM-related careers;
- employers can gain access to knowledgeable, talented people with strong STEM skills, increasing productivity, competitiveness and diversity;
- teachers of STEM subjects continually develop their STEM knowledge and experience, maximising their impact and own job satisfaction. Families and communities recognise the value of STEM to young people, encouraging and supporting them in STEM-related studies and careers.

4.2. Flexible and inclusive learning spaces

As faculty explore innovative approaches to teaching and learning, attention should be given to physical space. Environmental psychologists recognize that physical space can influence behaviour in both positive and negative ways [2]. While students benefit from a range of learning experiences [3], the traditional classroom, with its fixed seating arrangement and singular focus on the instructor, is best-suited for lecture. With faculty implementing alternative teaching and learning strategies, a traditional space constrains the effectiveness of more student centred approaches. Learning that is active, participatory, experiential and cooperative requires a flexible space. In this way, physical space is viewed as an agent of change [4].

Student-centred approaches to learning require a physical space that adapts to learner demands. Using modular furniture and accessible information technology better supports alternative approaches to teaching and learning. As instruction moves toward co-creation of the learning experience, the flexible, networked classroom provides an appropriate physical setting. Investment in flexible learning space design supports students and faculty and reinforces institutional commitment to educational excellence [5].

Creating inclusive environments involves systemic changes that require the strategic use of human and material resources. Schools, districts, and states must take deliberate action to broaden participation over the long term. These actions will vary at each level of the education system. Expectations and opportunities to learn STEM are set from the moment a child enters the classroom. Creating inclusive classroom learning environments is an essential yet underdeveloped skill. Professional learning for teachers should blend the elements of teaching STEM and broadening participation. It can include families and students to help educators appreciate families' commitment to education and understand students' thinking about STEM. Involving administrators can increase their awareness of the changes needed to broaden participation in STEM [6].

4.3. STEM opportunities and careers

Careers in the STEM fields include large sectors of our society, and hold roles for people who complete various levels of formal education. Two-year college degrees can lead to careers as technicians in computer manufacturing, and graduate diplomas in bioengineering can lead to careers in cutting edge biomedical and biotechnology research [7].

However, unlike non-technical fields, STEM careers require a path of achievement that starts with high school courses in Maths and Science [8]; these courses are known as gatekeepers to advancement. In fact, students need to leave high school academically prepared, with a sense of self-efficacy, motivation and commitment to persist until graduation in a STEM area major [9].

The last decade has seen considerable concern regarding a shortage of Science, Technology, Engineering and Mathematics (STEM) workers to meet the demands of the labour market. At the same time, many experts have presented evidence of a STEM worker surplus. A comprehensive literature review, in conjunction with employment statistics, newspaper articles, and interviews with company recruiters, reveals a significant heterogeneity in the STEM labour market: the academic sector is generally oversupplied, while the government sector and private industry have shortages in specific areas [10].

Science, Technology, Engineering and Mathematics workers drive innovation and competitiveness by generating new ideas, new companies and new industries. However, businesses frequently voice concerns over the supply and availability of STEM workers. Over the past 10 years, growth in STEM jobs was three times as fast as growth in non-STEM jobs (in USA). STEM workers are also less likely to experience joblessness than their non-STEM counterparts. Science, Technology, Engineering and Mathematics workers play a key role in the sustained growth and stability of the economy. Regardless of educational attainment, entering a STEM profession is associated with higher earnings and reduced joblessness. For college graduates, there is a payoff in choosing to pursue a STEM degree, and for workers, an even greater payoff in choosing a STEM career [11].

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5. Strategies for policymakers and school leaders for the implementation of innovative approaches to the teaching of Science at secondary school level

by Laura Capelli, Emanuela De Negri, Anna Siri

5.1. Science Education Policy-making

As our society becomes more interconnected and globally competitive, new economic chances often come hand in hand with complex challenges. Therefore, policymakers must involve all of society in research and innovation processes and offer the space for open, inclusive and informed discussions on the research and technology decisions that will impact citizens’ lives.

Policymakers need to better understand, and communicate, the transformative relationship between Science, innovation and society. It is still uncertain how the workforce for future markets and innovative industries in Europe will be provided. For young people to hope for a career in Science, Technology, Engineering and Mathematics it is compulsory to bring emerging technologies and make markets friendlier to the classroom, to stimulate their imagination.

This chapter is aimed primarily at science education policymakers. It identifies the main emerging issues involved in helping citizens access scientific debate; it provides guidance on how they can contribute to Science education; and it proposes a new framework for all types of science education from formal, to non-formal and informal approaches.

5.2. Emerging issues

Making Science education and careers attractive to young people is an ambitious purpose, aiming at drastically improving science and technological literacy in our society. Innovative formal and informal science education teaching and learning are important to raise both young boys' and girls' awareness of the different aspects encompassing science and technology in our society, and to tackle the challenges faced by young people when pursuing careers in Science, Technology, Engineering and Mathematics (STEM).

The quality of school education in Science and technology became crucial for governments. In particular, three are the key elements.

The first issue relates to the traditional role of Science in school, namely the identification, motivation and initial preparation of those students who will go on to further studies for careers in all those professional STEM fields. A necessary supply of these professionals is vital to the economy of all countries and the health of their citizens. They are recognised everywhere as key players in ensuring that industrial and economic development occurs in a socially and environmentally sustainable manner. In many countries, this supply is now decreasing seriously.

The second one is that sustainable technological development and many other possible society applications of Science require the support of scientifically and technologically informed citizens. Without the support and understanding of citizens, technological progress can all too easily serve a short term and sectional interests.

Sustainable development involves societies in ways that can often interact strongly, with traditional values, and therefore, making decisions about them involve major moral decisions. All students need to be prepared through their science and technology education to be able to participate actively as persons and as responsible human beings.

The third imperative derives from the changes that are resulting from the application of digital technologies that are the most rapid, the most pervasive, and probably the most widespread effect that Science has ever had on human society. We are all part of a global communication society. This is leading to profound changes in the World of Work and in what is known as the Knowledge Society. Schooling is now being challenged to contribute to the development in students of an active repertoire of generic and subject-based competences. Science and technology education needs to be a key component in developing these competencies.

5.3. Key recommendations

<u>Better conceptualising scientific literacy in curriculum and competence frameworks:</u>

- all elements of scientific literacy should be integrated into curricula and fostered across educational levels and academic disciplines (such as Science, History, Citizenship, Health, Media education). Scientific literacy includes the ability to think scientifically, apply knowledge in practice, critically assess information and actively engage in an informed democratic dialogue by using valid scientific evidence and scientific tools for reasoning. It goes beyond the mere acquisition of scientific knowledge. This extended understanding of scientific literacy has been widely taken up by recent EU [1][2] and national education policy strategies (EU's recent 'Future of Learning' package).

<u>Addressing the risks relating to the spread of misinformation and disinformation:</u>

- policymakers should disseminate scientific evidence on science-related issues and promote effective tools to detect, analyse and expose misinformation and disinformation [3]. Greater attention has to 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.

<u>Supporting innovation and lifelong learning in education for scientific literacy:</u>

- the development of scientific literacy and critical thinking should be considered in a lifelong learning perspective targeting both young and adult learners. Recent Eurobarometer survey results suggest that people with lower levels of education tend to be less concerned about important science-related issues such as climate change, and more vulnerable to disinformation [4];
- policymakers should consistently support public and private initiatives to promote Science among the population across Europe (courses, scientific and technical

museums, scientific literacy centres, scientific popularisation journals, science festivals, Fab Labs, Living Labs, networks) and ensure that they are accessible to socio-economically disadvantaged groups;
- policymakers should also encourage the collaboration of various stakeholders through Erasmus+ and Horizon 2020/Horizon Europe projects aimed at the design, piloting and exchange of new teaching practices to develop scientific literacy among all citizens.

Developing adequate instruments for assessing scientific literacy:

- existing tools for measuring scientific literacy are often focused on students' level of scientific knowledge and competences, leaving aside such elements as critical thinking and active engagement. The development of comprehensive assessment instruments could allow grabbing scientific literacy more holistically and a better understanding of what educational approaches can help develop it;
- policymakers should encourage the use of the existing research funding programmes (such as Horizon 2020/Horizon Europe) to fund projects exploring appropriate assessment instruments to better measure scientific literacy. Such projects should be multi-dimensional and involve the collaboration of various stakeholders including researchers, scientists, educators and businesses engaged in the design of digital assessment tools.

Building teachers' capacity to adopt scientific literacy:

- to educate scientifically literate students, one needs scientifically literate teachers. Effective implementation of innovative science teaching practices (e.g. inquiry-based science teaching, integrated science teaching practices and lessons outside of school walls) depend on teachers' capacity. Relevant training and professional development opportunities for teachers should equip them with the necessary competences to develop scientifically literate students;
- national education systems should also develop schools' capacity to promote a collaborative learning culture that motivates teachers and builds their competences to adapt to the changing needs of learners and society;
- policymakers should use the tools at their disposal to provide various professional development opportunities for the promotion of innovative science teaching methods and cross-curricular approaches to Science.

Encouraging access and equity in science education:

- policymakers should address socio-economic, gender and cultural inequalities to widen access and provide everyone with the opportunities to pursue excellence in learning and learning outcome;
- using information and communication technologies (ICT) in Science Education.

Technology-based teaching and learning can make many changes in school that require a proper planning and policy. The national ICT policies can serve several crucial functions. They provide a rationale, a set of goals, and a vision of how education systems run if ICT is integrated into teaching and learning process, and they are beneficial to students, teachers, parents and the general population of a given country.

It has been shown that the use of ICT in education can help improve memory retention, increase motivation and generally deepens understanding. ICT can also be used to promote collaborative learning, including roleplaying, group problem solving activities and articulated projects. ICT allows the establishment of rich networks of interconnections and relations among individuals.

Lack of adequate ICT equipment and internet access is one of the key problems that schools are facing now.

Several studies argue that the use of new technologies in the classroom is essential for providing opportunities for students to learn to operate in an information age. It is evident, as argued that traditional educational environments do not seem to be suitable for preparing learners to function or be productive in the workplaces of today's society.

Policymakers should consider the cost, provision and maintenance of ICT across the school system in terms of the educational benefit and equity it will bring to schooling in general, and to Science and Technology education.

Promoting participatory research and Open Science:

- the promotion of Open Science can improve public access to scientific information and engage scientists in the public debate. Additionally, it creates stronger links between Science and society and increases public trust in Science by engaging the general public in scientific activities and participatory research (Citizen Science);
- policymakers should further invest in participative research projects, based on the principles of Open Science, to bring Science closer to the public, stimulate scientists to take a more active part in science-related public debates, as well as education activities at schools, to combat the influence of misinformation and pseudo-science.

5.4. Conclusion

The world is changing rapidly [4]. The global competition and the technological developments have stimulated new patterns of social mobility and migration, greater inter-connectivity between and within societies and cultures and improved individual and community empowerment.

New demands on our institutions, businesses and civil society organisations are placing to meet the changing needs of the society and the workplace.

To meet these scientific and technological challenges, the European Union has set ambitious goals: to promote smart, sustainable and inclusive growth, to find pathways to create new jobs and to offer a sense of direction to our societies. This requires significant strengthening of our knowledge and innovation capacity and our creative capability as drivers for future growth.

Evidence shows that the European citizens, either young or old, appreciate the importance of Science and want to be more informed and that citizens want more science education. Over 40% believe that Science and Technological innovation can have a positive impact on the environment, health and medical care and basic infrastructure in the future.

This is a really exciting time to create opportunities for science learning, in formal, non-formal and informal settings.

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6. Guidelines for school leaders in secondary school STEM education

by Laura Capelli, Emanuela De Negri, Miglena Molhova-Vladova, Anna Siri

6.1. Teacher education and teachers’ professional development

This chapter is for school leaders, head teachers, school principals, team leaders, coordinators, etc., who want to know the main actions that have to be taken to improve the depth and quality of learning outcomes in science education [1][2].

From induction through pre-service preparation and in-service professional development, should the quality of teaching be improved to develop the quality of learning outcomes.

Continuous Professional Development should become a requirement and a right for all teachers throughout their teaching career.

Efforts should be made to attract more highly qualified and motivated people to become teachers and to enhance the status and prestige of the profession.

Greater emphasis should be given to closing the research-practice gap, by implanting science education research findings into teacher preparation, curriculum development, teaching and learning, and assessment for learning.

Appropriate approaches should be developed for teaching research ethics and raising awareness on research integrity.

Mechanisms should foster the support schools and teacher teams working with reflective, evidence-based approaches, e.g. team-based earning and pair/peer teaching between pre- and in-service teachers and other stakeholders, blended learning, curriculum innovation, teachers as responsible innovators and educational entrepreneurs.

Science education should be a crucial part of a learning continuum for all, from pre-school to active engaged citizenship.

Higher attention should be given to the value of all disciplines and on how interdisciplinarity (STEAM rather than STEM) can contribute to our understanding and knowledge of scientific principles and to solve societal challenges.

Educational institutions, at all levels, should boost understanding of the importance of acquiring key competences to ease the transition from “education to employability” [3][4], by:

- learning about Science through other disciplines and learning about other disciplines through Science;
- strengthening connections and synergies between science, creativity, entrepreneurship and innovation.

More importance should be placed on ensuring all citizens are equipped with the skills and competences needed in the digitalized world starting with preschool.

Specific attention should be given to projects and educational programmes that:

- stimulate creativity, innovation and entrepreneurship throughout the educational life-cycle;
- build on curiosity and develop the relevance of science education to learners' lives, including connections to societal challenges;
- develop innovative teaching and evaluation practices to support STEAM and inter-disciplinary learning with a focus on competences for science, innovation and education to employability.

6.2. Using information and communication technologies (ICT)

Integration of ICT into education plays an important role in simplifying and increasing student learning.

As the world becomes more inter-connected and competitive and as research and technological know-how expands, new opportunities along with more complex societal challenges arise. Overcoming these challenges will require all citizens to have a better understanding of Science and Technology if they are to participate actively and responsibly in science-informed decision-making and knowledge-based innovation. Enhancing the educational process to better equip future researchers and other actors with the necessary knowledge, motivation and sense of societal responsibility, it is mandatory to actively participate in the innovation process. Schools should enlarge the use of ICT to enrich science education, for all ages, in and beyond the classroom, including via accredited online courses and programmes in innovative formats, to support the different paces of learning and profiles of learners [5][6][7].

6.3. Linking schools with community Science organisations

Collaboration among 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 interest of science studies and science-based careers to improve employability and competitiveness.

Encourage "open schooling" where:

- schools, in cooperation with other stakeholders, become an agent of community well-being;
- families are encouraged to become real partners in school life and activities;
- professionals from enterprise, civil and wider society are actively involved in bringing real-life projects into the classroom;
- endorse partnerships among teachers, students, researchers, innovators, professionals in enterprise and other stakeholders in science-related fields, to work on real-life challenges and innovations, including associated ethical and social and economic issues;
- share guidelines on how to integrate responsibility and responsiveness into formal, non-formal and informal Science education, following the principles of CSR (Corporate Social Responsibility) and RRI (Responsible Research and Innovation);

- encourage partnerships that adopt networking, sharing and applying Science and Technology research findings amongst teachers, researchers and professionals across different enterprises (start-ups, SMEs, large corporations).

The link between scientists, researchers, science educators and the media should be strengthened to ensure more effective public communication, in a way that makes the underlying issues and consequences understandable by citizens. Citizens should be actively and directly involved in science research and innovation projects.

6.4. Conclusion

To summarize, successful developments in Science education are characterised and driven by:

- collaborations among school-teachers and external agents such as higher education institutions (HEIs), academies of science, research laboratories, business and community groups, various informal science-promoting actors e.g. science museums, enterprises as well as civil and society organisations etc.;
- cooperation when designing teaching-learning sequences and ICT-enhanced learning environments [10][11];
- robust teacher preparation and induction as well as long-term teacher professional development initiatives, all focused on student learning;
- active student and family engagement.

There is a wide range of interesting examples of innovation in Science Education practices, many of which have been tried out in classrooms or in professional development programmes and to a lesser extent in pre-service teacher education.

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ANNEXES

Appendix 1

DWS - Use of App or Web - for Student

All the data provided will be exclusively used for the poupose of the project.

* Required

1. **Which is your country? ***

   Mark only one oval.

   - Bulgaria
   - Greece
   - Italy

2. **Do you use any kind of Web Site to study? ***

   Mark only one oval.

   - everyday
   - twice a week
   - rarely
   - never

3. **Wich kind of Web Site mainly? ***

   Mark only one oval per row.

	a lot	sometimes	rarely	never
Own language				
Own language (i.e. english, french, …)				
Chemistry				
Maths				
Natural Science				
Physics				

4. **Do you use any kind of App to study? ***

   Mark only one oval.

   - everyday
   - twice a week
   - rarely
   - never

5. **Wich kind of App mainly?** *

Mark only one oval per row.

	a lot	sometimes	rarely	never
Own language	◯	◯	◯	◯
Own language (i.e. english, french, ...)	◯	◯	◯	◯
Maths	◯	◯	◯	◯
Physics	◯	◯	◯	◯
Chemistry	◯	◯	◯	◯
Natural Science	◯	◯	◯	◯

6. **Do you think the use of apps or web portal could be advantageous for your study habits?** *

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Maybe

7. **Do you think that through the use of apps and web portals you can improve your skills in:** *

Mark only one oval per row.

	Yes	No	Maybe
Chemistry?	◯	◯	◯
Maths?	◯	◯	◯
Physics?	◯	◯	◯
Natural Science?	◯	◯	◯

Appendix 2

DWS - Use of App or Web - for Teacher

All the data provided will esclusively be used for the poupose of the project.

* Required

1. **Which is your country?** *

Mark only one oval.

- Bulgaria
- Greece
- Italy

2. **Do you use any kind of Web Site to teach?** *

Mark only one oval.

- everyday
- twice a week
- rarely
- never

3. **Wich kind of Web Site mainly?** *

Mark only one oval per row.

	a lot	sometimes	rarely	never
Own language				
Own language (i.e. english, french, ...)				
Chemistry				
Maths				
Natural Science				
Physics				

4. **Would you suggest your students to use any kind of App?** *

Mark only one oval.

- everyday
- twice a week
- rarely
- never

5. **Wich kind of App mainly?** *

Mark only one oval per row.

	a lot	sometimes	rarely	never
Own language	⬭	⬭	⬭	⬭
Own language (i.e. english, french, …)	⬭	⬭	⬭	⬭
Maths	⬭	⬭	⬭	⬭
Physics	⬭	⬭	⬭	⬭
Chemistry	⬭	⬭	⬭	⬭
Natural Science	⬭	⬭	⬭	⬭

6. **Do you think the use of apps or web portal could be of any advantages for your students?** *

Mark only one oval.

- ⬭ Yes
- ⬭ No
- ⬭ Maybe
- ⬭ Other

7. **Do you think that you can improve your teaching through the use of apps and web portals in:** *

Mark only one oval per row.

	Yes	No	Maybe
Chemistry?	⬭	⬭	⬭
Maths?	⬭	⬭	⬭
Physics?	⬭	⬭	⬭
Natural Science?	⬭	⬭	⬭

8. **Do you think that using apps or web portal could simplify the study of students?** *

Mark only one oval.

- ⬭ Yes
- ⬭ No
- ⬭ Maybe

9. **Do you think that using apps or web portal could leave your students more free time?** *

Mark only one oval.

- ⬭ Yes
- ⬭ No
- ⬭ Maybe

Appendix 3

DWS - Student questionnaire

All the data provided will be used only for the poupose of the project.

* Required

1. **Name and Last Name (optional)**

2. **What is the names of your schools?**

3. **What is your classroom?**

4. **How many exercises did you do?** *

   Mark only one oval.

   - ◯ 1-5
   - ◯ 6-10
   - ◯ >10

5. **Which app did you use?** *

   Check all that apply.

   - ☐ Android
   - ☐ iOS
   - ☐ Web portal

6. **The app was** *

Check all that apply.

	very good	good	no bad	bad
-	☐	☐	☐	☐

7. **What kind of exercises did you carry out?** *

Check all that apply.

- ☐ Maths
- ☐ Physics
- ☐ Natural science

8. **Comments and/or questions**

____

____

____

____

____

Appendix 4

DWS - Exercise suggestion

The project will be very glad for your suggestion!

* Required

1. **Category** *

   Mark only one oval.

   ◯ Maths
   ◯ Physics
   ◯ Natural Science

2. **Topic (e.g. equation, forces, mass, environment, ...)** *

   ____

3. **Suggestions for exercise** *

   ____
   ____
   ____
   ____
   ____

4. **Name (optional)**

   ____

5. **Email (optional)**

   ____

Appendix 5

DWS - Teacher questionnaire

All the data provided will be used only for the poupose of the project.

* Required

1. **Name and Last Name (optional)**

2. **What is the names of your schools?** *

3. **How many exercises did you check?** *

   Mark only one oval.

   - ◯ 1-5
   - ◯ 6-10
   - ◯ >10

4. **Which app did you use?** *

   Check all that apply.

   - ☐ Android
   - ☐ iOS
   - ☐ Web portal

5. **The app was** *

   Check all that apply.

	very good	good	no bad	bad
-	☐	☐	☐	☐

6. **What kind of exercises did you carry out?** *

Check all that apply.

- [ ] Maths
- [ ] Physics
- [ ] Natural science

7. **If you create any exercise ...** *

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongle agree
the procedure is clear	⬭	⬭	⬭	⬭	⬭
the procedure is easy	⬭	⬭	⬭	⬭	⬭
[it is easy to include more than one answer to the questions	⬭	⬭	⬭	⬭	⬭
it is easy to insert the formulas	⬭	⬭	⬭	⬭	⬭
it is easy to insert images	⬭	⬭	⬭	⬭	⬭
I do not understand when to insert the scores	⬭	⬭	⬭	⬭	⬭
inserting an exercise takes a long time (at least 1 hour)	⬭	⬭	⬭	⬭	⬭
I enjoy inserting the exercise	⬭	⬭	⬭	⬭	⬭

8. **What aspects of the web portals were most useful or valuable?**

____

____

____

____

____

9. **What aspects of the App were most useful or valuable?**

____

____

____

____

____

10. **How would you improve DWS web portal or apps?**

Appendix 6

Do Well Science Project

Project Evaluation
by end users

This questionnaire is addressed to the three main target users of the project: School Directors, Secondary School teachers, Policy Makers.

SECTION A: PERSONAL and PROFESSIONAL DETAILS

Name: (optional)

Country:

☐School Director ☐Teacher ☐Policy Maker

☐Other, please specify ………

Section B: Evaluation of the Do Well Science intellectual Output

B.1 STEM Teaching and Learning Package

Please tick one of the numbers below where 1 = Poor and 10 = Excellent

Usability	①②③④⑤⑥⑦⑧⑨⑩
General organization of structure	①②③④⑤⑥⑦⑧⑨⑩
Easiness of navigation	①②③④⑤⑥⑦⑧⑨⑩
Scientific reliability	①②③④⑤⑥⑦⑧⑨⑩
Didactical Appropriateness	①②③④⑤⑥⑦⑧⑨⑩
Usefulness and Transferability	①②③④⑤⑥⑦⑧⑨⑩
Attractiveness for students	①②③④⑤⑥⑦⑧⑨⑩

B.2Is the Package useful for you? Why?

____

____