CIDREE
Consortium of Institutions for Development and Research in Education in Europe

Authors: Gilles Aldon, Andreja Bacnik, Hannelore Baeyens, Els Belien, Ola Berge, Michiel Doorman, Melinda Filo, Robert Fisch, Ove Edvard Hatlevik, Kim Heuskin, Gerti Janaqi, Ian Menzies, Sid Mysore, Marija Naletilic, Andrea Pallag, Dorina Rapti, Serge Schaetzel, Sophie Soury-Lavergne, Maja Stojkic, Mojca Suban, Maria Szaba, Jos Tolboom, Attila Varga, Danica Vasilj, Luc Weis

Editor: Sid Mysore

Coordinators: Patrick Krier, Yannick Bartocci

SCRIPT Editorial Team: Anne-Marie Antony, Fabienne Abens, Yannick Bartocci, Änder Brepsom, Paul Fayard, Jessy Medinger

Graphic Design & Layout: Richard Heinemann

Print Management: Alain Schintgen

CIDREE National Coordinator: Amina Afif

ISBN: 978-99959-1-126-3

How to cite this publication: Mysore, S. (Ed.) (2018). International Approaches to STEM Education. CIDREE Yearbook 2018. Luxembourg: Service de Coordination de la Recherche et de l'Innovation pédagogiques et technologiques

Printed in Luxembourg by: eXe Group. Troisvierges

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President's Foreword

Luc Weis

Welcome to the CIDREE yearbook for 2018, International Approaches to STEM Education. Through the publication of this yearbook and the related launch conference, we celebrate yet another year of CIDREE networking. CIDREE was launched in 1990 as a self-managing network of educational bodies that actively support national policy-making. The collective experience of this unique network allows its members to gain valuable insights as well as pinpoint quality in educational policies. Through the knowledge thus gained, members seek to impact the schools, curricula, teaching and assessment regimes within their own national systems.

A central objective of CIDREE has always been to facilitate the sharing of information among the uniquely placed member institutions, and to provide opportunities to foster new ideas through collaborative activities. One of these truly collaborative activities is the annual edition of the CIDREE Yearbook. Collectively, the network has chosen a topic to which educational institutions from ten European countries have contributed current and relevant case-studies and frameworks, the outcomes of which will be discussed at the launch conference in Luxembourg and, hopefully, beyond.

Looking at the various chapters of this Yearbook, it becomes obvious that STEM education is a policy priority in many European countries. Society, and with it schools, are changing rapidly due to technology, digitalization and scientific breakthroughs. New skillsets and competencies, new forms of governance as well as new organizational capabilities are required. National strategies not only focus on fostering scientific elites but also on the promotion of scientific culture: All citizens need to be able to "think like a scientist or an engineer", and need to develop the necessary confidence and ability to confront science and technology related challenges. That is why programmes are being developed throughout Europe that aim to spark interest in science among young people who might not benefit from such stimulation from their background alone, and to encourage and support students' decision to pursue further studies in science.

On the one hand, science education promotes an understanding the world surrounding us and provides means to master the challenges of daily life. On the other hand science education is increasingly called to attract people to sectors that are deeply threatened by a shortage of skilled professionals. Few will debate that *"solutions to the most complex problems that humanity faces today – from climate change to inter-cultural communication and managing technological risks – will come from creative individuals who are willing to engage with these difficult issues and have the ability to do so."*[1]

[1] *OECD (2016), PISA 2015 Results (Volume I): Excellence and Equity in Education. PISA, OECD Publishing, Paris. P. 266.*

At this point, I would especially like to thank Sid Mysore, the Yearbook's editor, and also the other collaborators at SCRIPT for their timely initiative and the work they have put in the production of the CIDREE Yearbook 2018. And, of course, my sincerest thanks also go to all the authors who have contributed to this unique book that collects examples of initiatives in STEM education from ten European countries.

This yearbook reflects the richness of the membership in CIDREE at its best.

Luc Weis

President CIDREE 2018
Director SCRIPT, Department for Coordination of Research and Pedagogical and Technological Innovations

Editorial Introduction

This Yearbook provides an insight into Science Education strategies, innovations and practices from several European countries. Throughout the eleven articles, sets of authors from diverse backgrounds and specialisations, in and around education, offer perspectives on the educational landscape and projects that promote and cultivate scientific learning in the 21st century.

The articles illustrate the dichotomy that characterises science education well:

> *"We need science education to produce scientists, but we need it equally to create literacy in the public. Man has a fundamental urge to comprehend the world about him, and science gives today the only world picture which we can consider as valid. […] Literacy in science will enrich a person's life.[1]"*

It becomes clear when going through the articles, that the education systems sampled in this international publication are determined to maintain and improve the performances their students achieve in science. Simultaneously, these systems are increasingly adapting to technology and involving students in a debate on scientific culture. Inquiry-Based Learning, student-centered learning scenarios and technology-mediated courses are but some of the keywords that can be found at the focus of the published contributions.

The articles explore the diverse challenges faced by educational actors in different areas of the science education landscape. Some articles document the development of educational strategies that encompass formal as well as non-formal domains of education, the implementation of these strategies in educational policy and the challenges faced in applying the policies to STEM curricula.

Other articles focus on the concepts popular in modern science education such as Inquiry-Based Learning and the integration of artistic creativity in the STEM curricula, known as the STEAM approach.

Curricular development activities are emphasized in yet other articles, that present the process, implementation and challenges of basing common core curricula on learning outcomes and implementing competency-based learning in mathematics.

The Yearbook also includes articles on the use of technology in the mathematics curriculum, a subject that has been regularly discussed in international expert groups, and fittingly, the last article illustrates the discussions and results of one of these meetings on the subject.

Throughout the Yearbook, the international contributions allow us to gain insight into the perspectives of policy-makers, administrations, committed teachers and engaged learners, all actively investing in and changing the dynamic field of science education.

[1] *Attributed to Hans Albrecht Bethe, (July 2, 1906 – March 6, 2005), German-American nuclear physicist*

A glimpse into the Yearbook

Authors of ten European nations have contributed eleven articles to the Yearbook 2018: Albania, Bosnia and Herzegovina, Flanders, France, Hungary, Luxembourg, Norway, Scotland, Slovenia and The Netherlands. Here is a quick preview of the book's contents, country by country.

Luxembourg

This general overview of the science education landscape in Luxembourg illustrates the common core of STEM education and describes the different pillars of national STEM strategy. Case studies within each of these pillars illustrate the interconnectedness of the STEM domain and its actors and highlight the necessity for a holistic approach to science education. From formal to non-formal education as well as teacher training initiatives, science teaching in Luxembourg has evolved a lot in the recent years. In this broad overview, the initiatives of the Ministry of Education, Childhood and Youth are illustrated as well as the challenges that lie ahead to consolidate innovative projects and make relevant science education available for students of all ages and backgrounds. Science education in this article is presented as a dual tool, one to foster excellence and improve science literacy in general.

Luxembourg

The second article from Luxembourg presents aspects of a new specialization section with a focus on information and communication technology. This specialization places importance on a project-based approach. The section is characterized by the inclusion of interdisciplinary learning scenarios and by the time dedicated to developing problem-solving competencies. The article presents the new Project Management subject created to promote these aspects of the specialization. The authors also include a case study of the implementation of IT and innovative methodology in the more conventional context of the mathematics curriculum.

Scotland

Ian Menzies describes the STEM Education and Training Strategy that the Scottish Government launched in 2017. This five-year strategy sets out to transform STEM provision across all sectors and is closely aligned to significant reforms in Scottish education aiming to promote excellence and equity. This article presents the process of developing the educational strategy and its alignment with other policy areas. It also discusses the key challenges to its implementations and how national actors tackle the issues of gender balance, equity and youth unemployment.

Flanders

The Flemish contribution describes the evolution of science education in Flanders and sketches the vision driving the development of a new STEM curriculum. An analysis of the implementation of problem-solving, research and design skills in current curricula provide an insight into Flemish science education. The article also presents initiatives that have been undertaken to improve integration and quality of science education, specifically the development of a STEM framework as well as new didactic models for science learning. Finally, by sketching the vision for an updated Flemish STEM curriculum, the objectives of this competency-based framework are discussed, and their implementation illustrated.

Slovenia

This article focusses on the concept of inquiry-based learning and its relevance in science and mathematical education. The authors offer definitions of inquiry-based learning in general as well as science specific contexts and discuss the phases of inquiry-based learning. The implementation of inquiry-based learning in the STEM curricula in Slovenia as well as the projects and teacher training necessary to advance this approach to science and mathematics education.

Hungary

The Hungarian article discusses the duality between modern and classical approaches to science education. Several initiatives link STEM to creativity and art, from top-down interventions to the support of innovative practitioners and partnerships. The cooperation with research institutes as well as non-governmental organisations and private entities enhance the system with innovative approaches to STEM education as illustrated by the examples provided by the authors.

Bosnia and Herzegovina

The development of a Common Core Curriculum in Bosnia and Herzegovina based on learning outcomes which was undertook from 2012 to 2016 is presented in this article on the implementation of educational strategy. By analysing the national objectives and European frameworks, key competencies were defined as well as different strands of education, such as Communication, Art, Natural Sciences, etc. Furthermore, a set of sectors group subject matter in real life contexts. The article illustrates the process by exhibiting the indicators for the end of year outcomes, according to the students age and strand of education.

Albania

In this article, the authors describe the process undertook in Albania to structure the teaching of mathematics by implementing a framework of six mathematical competencies, from Problem-solving to Mathematical Modelling and the use of technology in mathematics. The authors describe these six competencies and provide insight into the key indicators each competency refers to. Examples of learning scenarios targeting the development of these competencies illustrate the implementation of this framework in mathematics courses.

France

The authors of the French article highlight the teaching and use of computer science in the French curriculum for mathematics and technology. Following an interdisciplinary approach, technological tools are complementary to theoretical teaching in developing mathematical competencies. Computer Science and Computational Thinking are integrated in different learning scenarios of which the article illustrates examples from integrating robotic learning tools to teaching algorithms through games.

Norway

The presence of informatics and communication technology in the curricula of Norwegian primary and secondary schools and the central policy initiatives relative to ICT in education are the focus of this article by the authors Ola Berge and Ove Edvard Hatlevik. A case study on the application of IT to solve challenges faced in specialized education in sparsely populated areas in Norway as well as Internet-based education for highly motivated mathematics students demonstrate how the integration of new technology can flip the classroom and innovate learning scenarios and teaching practices.

Netherlands

This article contributed by the Netherlands presents the discussions and ideas collected by an international group of European STEM curriculum experts. The international discussion group studied the challenge of creating more coherence in the STEM education domains in general and focused on improving computer-based learning in mathematics curricula. The integration of informatics as a part of the STEM curriculum is also discussed and the results of this meeting are synthesized in form of a survey of the participants.

Conclusion

As illustrated by the diverse articles, science education is as multi-facetted as science itself. Science has never progressed at a speed as accelerated as today, and the competencies that our education systems impart to students must allow them to become dynamic actors in their future professions. Educators and policy-makers are using many different tools to connect students to the scientific achievements that are part of our shared culture as well as motivate these students to excel in the sciences. Most importantly, not knowing where scientific development will lead us, students should be able to adapt their skillset and maintain an attitude of continuous learning.

Our rapidly changing society and the challenges that it faces today require our students to analyse and interpret scientific results and to use these to shape their decisions and actions as citizen, be it in sociological, ecological or scientific domains. The rapprochement of these contexts to our science curricula will determine if students perceive the STEM content of their education to be relevant to their lives.

The aspiration of the ongoing work described in this CIDREE Yearbook of 2018, and the insights shared by our contributors into their fields of expertise will hopefully provide grounds for discussion and reflection to all involved in shaping science education, policy-makers and educators alike.

Sid Mysore
Editor

Authors

Luc Weis

Luc Weis received the equivalent of a Master's degree in Languages from the University of Heidelberg in 2001. For 12 years he worked as a teacher in various high schools in Luxembourg and he was active in teacher training at the University of Luxembourg from 2006 to 2013. In 2013, he joined the Ministry of National Education, Children and Youth of the Grand Duchy of Luxembourg (MENJE). Since 2015, he leads the Department for the Coordination of Research and Educational and Technological Innovation (SCRIPT), which is an organization of the MENJE.

He is responsible for executing the mission of SCRIPT which is implementing and promoting innovation in education and technological research, maintaining the quality of education in schools and colleges, and editing text book for teachers and learners in Luxembourg.

Sid Mysore

Sid Mysore received Masters' degrees in Fundamental and Financial Mathematics and in Informatics from the University of Paris in 2009. He worked as a mathematics and informatics teacher for 7 years in a pilot project secondary school in Luxembourg before joining the Department for the Coordination of Research and Educational and Technological Innovation (SCRIPT).

He coordinates innovation projects and initiatives in the fields of Science and IT in Education.

Abstract

This general overview of the science education landscape in Luxembourg illustrates the common core of STEM education and describes the different pillars of national STEM strategy. Case studies within each of these pillars illustrate the interconnectedness of the STEM domain and its actors and highlight the necessity for a holistic approach to science education. From formal to non-formal education as well as teacher training initiatives, science teaching in Luxembourg has evolved a lot in the recent years.

In this broad overview, the initiatives of the Ministry of Education, Childhood and Youth are illustrated as well as the challenges that lie ahead to consolidate innovative projects and make relevant science education available for students of all ages and backgrounds. Science education in this article is presented as a dual tool, one to foster excellence and improve science literacy in general.

A brief introduction to STEM education in Luxembourg

Historical and Industrial Context

A country shaped by siderurgy in the beginning of the 20th Century

Throughout Luxembourg's recent history, its activities in scientific and industrial domains have shaped the country's identity.

Starting at the end of the 19th century, when iron ore was discovered in the south of the country, the steel industry made its mark on its landscape, not only through the blast furnaces and towering chimneys, but also by inviting generations of immigrant workers, first of German, then Italian origin to augment the cultural identity of rural Luxembourg. These industries were instrumental in developing and spearheading Luxembourg's political strategy of fostering a greater and stronger Europe: the small country with a large contingent of export quality steel has been a proponent for ever-growing trade unions and helped pave the way for the first European Coal and Steel Community, precursors of the European Union of today.

But even with immigration the demand for skilled labour could not be met; to respond to the massive demand of the steel industry for qualified workers, the industry, hand in hand with local and national administration, instituted from 1899 onwards so-called "Léierbuden"[1] (Learning Shacks), providing students the opportunity to learn the skills necessary to find employ in the steel industry. Students in those schools preparing for a career in the steel industry would even be paid a modest salary – an incentive that led many young people in Luxembourg into the steel industry.

In 1974, the steelworks and iron ore mines employed around 25,000 people, equating to 16% of the total workforce of the Luxembourg economy .

The golden age of the European steel industry in the mid-20th century waned, however, following the steel crisis of the 1970s, and progressively lost its driving force in the Luxembourg economy.[2]

Even though the last blast furnace closed in 1997, and the last "Léierbud" shut its doors in 2013, a generation of specialists in steel production and management made sure Luxembourg still enjoys a privileged seat at the table of the international steel industry. For instance, Paul Würth SA, founded in 1870 by a young Luxembourgish engineer, is an international leader in the design and implementation of blast furnaces and operates in steel producing locations worldwide. Furthermore, Luxembourg is the seat of Arcelor-Mittal, the steel behemoth that resulted from the successive fusions of the Luxembourgish Arbed, Spanish Aceralia, French Usinor and Indian Mittal Steel.

[1] *Arbed (Hg.), Un demi-siècle d'histoire industrielle 1911-1964, Luxembourg 1964. P. 258-259.*

[2] *www.luxembourg.public.lu/en/investir/secteurs-cles/industrie/siderurgie/index.html*

Nonetheless, this episode in Luxembourg's history not only contributed to the economical wealth of the country, it also profoundly marked the attitude the country took to developing its activities in further economic sectors.

Gearing the educational system for industrialisation[3]

The national education system learned to adapt to the economic realities of the industrial age.

But throughout the 20th Century, science curricula tended to focus on providing the foundations for the professional training of a small number of scientists and engineers. In highschools, the sections B (mathematics) and C (natural sciences) included classical studies in Latin but specialized in scientific subjects and allowed the students to pursue further studies, which were not open to students from other streams. These academic choices, originally only taught at boys' schools, were opened to girls in 1968, at the same time when the separation of girls' and boys' education was abolished.

The accent in those sections is placed on facts, laws or theories related to the various disciplines of science rather than the broad paradigms and the inter-disciplinary aspects related to epistemic and procedural knowledge. Educators tended to equate the students' ability to master those facts and theories with their ability to continue to study science beyond compulsory education, and the curricula was not geared to encourage every student to engage with science.[4]

[3] *Les 400 ans de l'Athenée du Luxembourg, G. Trausch (2003)*

[4] *OECD (2016), PISA 2015 Results (Volume I): Excellence and Equity in Education. PISA, OECD Publishing, Paris*

The balance between sciences and languages in education

One cannot discuss education in Luxembourg without mentioning its peculiar trilingual situation.[5] Whereas the statistics show that in 2016/17 42,5% of students in Luxembourgish education system were foreigners, the percentage of students speaking Luxembourgish at home is progressively decreasing and was down to 41% in the same year.[6]

As such, for Luxembourg, this trilingualism is vital, both because of the intensive exchanges with its neighbouring countries, and because of the geographical location of the country at the crossroads of the two major German-speaking and French-speaking linguistic areas. Language teaching therefore occupies a central place in the Luxembourgish education system.[7] Throughout a child's school career, French and German are compulsory languages from primary education onward. English is also compulsory and is taught during secondary school.

[5] *The official languages of the Grand Duchy are Luxembourgish, French and German. The language of communication between Luxembourgers is Luxembourgish, the national language. The main language of communication between Luxembourgers and foreign-language fellow citizens is French.*

[6] *MENJE. (2018). Luxembourgish education system – Key figures 2016-2017. Retrieved from http://www.men.public.lu/catalogue-publications/themes-transversaux/statistiques-analyses/chiffres-cles/2016-2017/fr.pdf*

[7] *MENJE. (2017). Languages in theLuxembourg schools. Retrieved from http://www.men.public.lu/fr/themes-transversaux/langues-ecoleluxembourgeoise/index.html*

To illustrate the scope of language education, a student of the Section B in an ESC (Enseignement Secondaire Classique), specializing in mathematics and informatics would still attend an important proportion of language courses (French, German and English) per week in the final three years of secondary education. The amount of language courses over the three years of specialisation in mathematics and computer science is equivalent to the combined class time dedicated to the two specialisation subjects.[8]

The scientific sections of the ESG (General Secondary Education), due to its industrial and technical heritage, do include more hours of technical and scientific classes.

This culturally significant characteristic of Luxembourgish education puts certain constraints on STEM education in general. Inquiry based learning and student-centered approaches leading to deeper learning are inherently time consuming. Scaffolding lessons and the integration of student input takes more time to accomplish than passing on information through direct instruction. Especially in the final years leading up to centralized testing, teaching time becomes a valuable commodity which influences the strategy teachers adopt with respect to STEM education.[9]

[8] *Synthesis of syllabus tables from the official programs for classical secondary schools*

Class level	**3e**	**2e**	**1e** *(final year)*	**Total**
Language lessons/ week	9 *(3 each)*	9 *(3 each)*	6 (*choice of 2 languages)*	**24**
Mathemat-ics lessons/ week	6	7	8	**21**
Informatics lessons/ week	0	1	2	**3**

[9] *Inquiry-Based Learning: Teaching Students to be Better Consumers of Information, Chelsea Hasenpflug*

The common core of STEM education

Luxembourgish students' pre-secondary education (École fondamentale) encompasses two years of compulsory preschool (Cycle 1) and six years of primary school: Cycle 2, 3 and 4. Each of these Cycles spans two years. After primary school, students are oriented towards either classical or general secondary schools which cover 7 years of studies.

In the following article the abbreviation ESC is used to refer to classical secondary schools (Enseignement Secondaire Classique) a stream that includes seven years of secondary education (counted from 7 down to 1) and which leads to the final diploma of classical secondary studies and primarily prepares students for university studies.

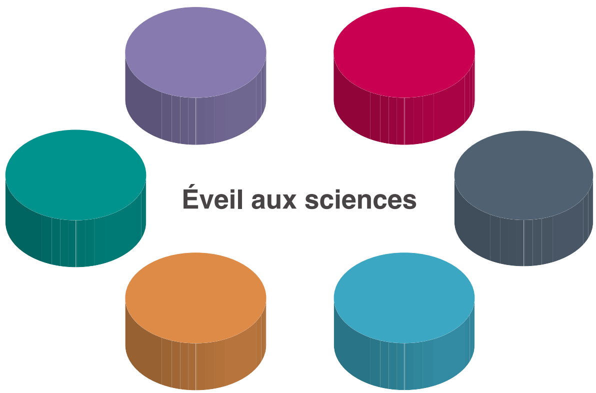
General Secondary Education (ESG) includes various divisions of industrially influenced studies over a span of seven years. Students of certain divisions are qualified for further studies while others are certified with professional diplomas. The ESG also includes a path of preparation (ESG-PREP), an educational pathway specifically for students who have not acquired the required competency bases at the end of Cycle 4 of primary education.

Students in an ESC follow a common orientation cycle of 4 years before choosing a specialisation section for the final three years. Students in an ESG choose their specialisation section a year earlier.

The common core of STEM education

During primary school, “Éveil aux sciences” (Initiation to science), a course which spans the Cycles 2 and 3 years of pre-secondary education, covers a variety of scientific and civic subject matters and promotes the development of certain competencies associated with STEM education.

Over the eight years, six main competencies are developed, in seven scaffolding levels:[10]



- Exploring phenomena
- Gathering and exploiting information in a targeted fashion
- Using critical judgement
- Establishing interrelations
- Imagining, conceiving and executing a project
- Interacting by using different communication methods

These competencies are developed while treating subject matter which is arranged in six fields:

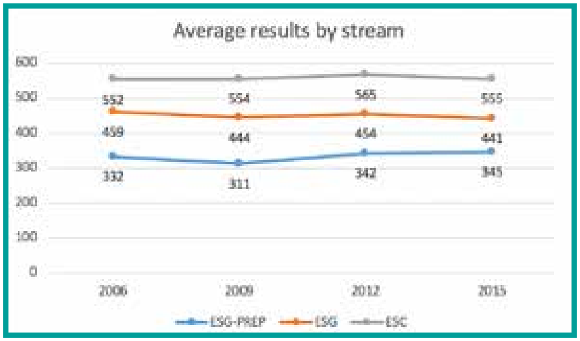
- Man
- Nature
- Technology
- The child and its environment, citizenship
- Space
- Time

These fields are revisited in each cycle, progressively increasing the complexity of the subject matter. Science in this syllabus is associated with practical skills and differs in this aspect from science education and abstract problem-solving competencies. However, this approach integrates subjects like history, geography, and civic instruction.

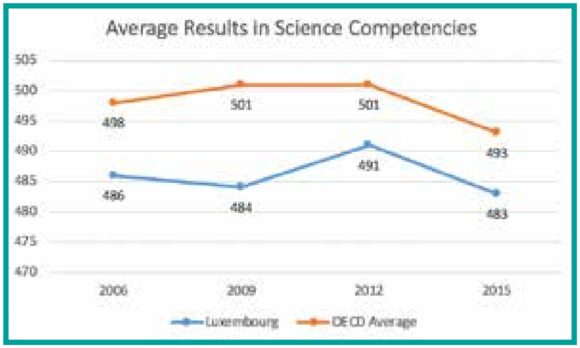
[10] *Plan d’études (Syllabus of 2011, Chapter Éveil aux Sciences) men.lu*

PISA

The PISA results relative to science education show that the results achieved by students did not significantly change over time when comparing 2006 to 2015. Interestingly, the only stream of education that noted a significant positive change is the stream of modular preparatory courses. This stream aims at providing students with difficulties in certain subject areas the means to integrate general education studies.



Average trends throughout the education system show similar values, documenting a statistically non-significant loss of three points over the years from 2006 to 2015, with a significant dip of 8 points between the years 2012 and 2015.



Luxembourg students express more pleasure and interest in natural sciences than the previous years, overtaking the OECD average in the span between 2006 and 2015. However the instrumental motivation associated with STEM knowledge and the interest in STEM careers has not evolved as positively as the OECD average has in the previous years: Luxembourg students attain 57 percent in comparison with the OECD average of 65. Student's epistemic beliefs fall similarly behind international average values with 74 percent compared to the OECD's 82 percent average.

Given the expected growth in science-related employment worldwide, the promotion of science careers and the cultivation of a scientific approach need to be developed further.

STEM strategy and policies

The policies of the STEM strategy pursued by the Ministry of National Education, Childhood and Youth (Ministère de l’Éducation, de l’Enfance et de la Jeunesse, MENJE) are structured in 6 interdependent fields of action.

1. **Scientific culture**
   Encouraging positive attitudes towards learning science among students of all backgrounds
2. **Educational Landscape**
   Mapping and connecting non-formal and semi-formal learning environments
3. **Curriculum development**
   Improving content, relevance and coherence in science education
4. **School development**
   Student-centered, and inquiry based science learning for K-13
5. **Empowering teachers**
   Enhancing know-how, ressources and attitudes
6. **Nurturing excellence**
   Cultivating scientific experts

1. Scientific culture

In Luxembourg, numerous initiatives and programs target the promotion of scientific culture, in schools, non-formal education contexts and in public settings. Hereunder a selection of recent initiatives to illustrate the measures taken to improve the plethora of science learning opportunities students can access.
→

ESERO

Luxembourg has joined the network of European Space Education Resource Offices (ESERO) coordinated by the European Space Agency (ESA), which will provide learning material and inspiration for teachers wishing to bring space into the classroom. The context of space not only captures children's imagination like few other subjects, but also is aligned with Luxembourg's recent investments in the commercial space industry. Luxembourg has recently created its own Luxembourg Space Agency (LSA) which aims to not only promote the industrial space sector but also generate interest in STEM subjects that contribute to the development of the field.

↑ ***Picture 1:*** *Luxembourg Science Museums and Centres*

↑ ***Picture 2:*** *Luxembourg Science Center, Phase 2 Project Renderings*

The ESERO initiative is hosted by the Luxembourg Science Center. This newly developed project combines Luxembourg's industrial heritage with a hands-on science education environment. The Science Center hosts not only several state-of-the-art exhibits in the industrial campus and halls of the ARBED, Luxembourg's steel behemoth of the past, it also provides workshops in numerous STEM domains, such as mathematics, plotting and 3D printing, chemistry, kitchen experiments, etc. The Science Center's objective is to get every class in the country to attend at least one workshop a year. Next to these classical science museum activities, this Science Center also offers students the opportunity to discover several professions and follow vocational courses in soldering, mechanics and many more. It is thus quite fitting that this institute is located in the halls of the now defunct industrial schools of the Steel industry. In its first year, the Science Center counted over fifty thousand visitors.

Especially the National Museum of Natural History (Musée Nationale d'Histoire Naturelle) has a long history of providing learning opportunities of a high quality to students of all ages. The MNHN, through its Panda Club and Science Club offers a treasure trove of afternoon activities, field trips and study vacations, which allow children of different age groups to explore their surroundings and learn about palaeontology, geology and natural sciences. Teachers can request the Museum to send the Science Truck to their school, which brings the museum staff to local primary schools. The activities and the Science Truck are very popular with teachers and students alike due to the successful mission of the Museum staff to engage with schools and teachers and compliment the national syllabus with quality content.

The Museum also organises the Science Festival every two years, which invites research institutes and schools all over the country to meet and present their science experiments.

↑ ***Picture 3:*** *National Museum of Natural History, picture by: http://vision.lu/*

Science Communicators

Next to the larger museums, which provide a lot of content, many smaller museums, workshops, discovery parks provide STEM learning opportunities to students. The resources put in motion and the amount of people competent in science and willing to share this passion with the next generations are considerable. Many of these entities have conventions with the MENJE that formalize the collaboration while others operate independently. In the last years, the MENJE has progressively started to track these activities and has started to actively reach out to these Science Communication experts. To this effect, the MENJE collaborates with the initiative of the National Research Fund (Fonds National de la Recherche, FNR) to organize get-togethers for all the Science Communicators in Luxembourg. During these gatherings, educators present their objectives and program. Grouped in thematic discussion rounds, the participants had the opportunity to express their needs and the obstacles they face. The MENJE uses these networking meetings to identify opportunities for the education system as well as to offer help promoting their activities to students, teachers and schools.

For the last two years, the Ministry of National Education, Childhood and Youth's Department for the Coordination of Research and Innovation in Pedagogy and Technology (SCRIPT) has organised the Luxembourg Science Week, which provides the Science Communicators with a platform where they can register their events and promote their activities and entities. Students and teachers are encouraged to attend or host these workshops and cultivate the proximity between the worlds of formal and non-formal education.

Especially when confronted with a curriculum that allots only limited time to student-centred inquiry-based STEM education, these non-formal activities play an important role in forging students' impressions of scientific activity. As students are not graded during these experiments, they become more process and less result-oriented – science is equated with fun and fulfilment, an important factor in fostering interest for STEM careers.

2. The science education landscape

The promotion of scientific culture in Luxembourg schools is supported by a large effort by teachers and volunteers, under the banner of schools and of independent non-profit organisations. Many, if not most of these organisations, are collaborating with the MENJE and obtain support, either in form of financial grants and/or by attributing teachers' work hours to these organisations.

Makerspaces

On a more non-competitive note, a recent development that has seen a lot of popularity is the creation of a network of Makerspaces. This initiative of the MENJE promotes the creation and staffing of creative hubs in schools and campuses throughout the country. These hubs each have their own speciality or specialities, such as electro-technical engineering, 3D printing, television programming or robotics and many more.

Teachers, volunteers and administrative personnel share the task of staffing the spaces (Spacekeepers) and guiding students in executing their own scientific and creative projects. As of this year, 25 makerspaces exist in Luxembourg and an ever-growing network of Spacekeepers and student makers meet twice a year in large science fairs to show off their creations and exchange inspirations.

These makerspaces are a boon to Science Culture in Luxembourg Schools as they not only provide students means to build machines and create art of their own design but can house many other projects. These Makerspaces give access to tools and guidance that kids may require to work on private and school science projects and most open their doors out of school hours to the public.

Code Club and similar non-profit organisations

This non-profit organization, which federates volunteers, teachers and external professionals, imparts the basics of programming to children in weekly one-hour programming sessions. This initiative is active in several communes and caters to students of primary and lower secondary school.

These sessions are part of a worldwide network of Code Clubs and let students gain a first insight into coding as well as electro-technical skills such as soldering, etc. Similar initiatives exist, where IT professionals, teachers and even older students provide free courses for kids either at home or in collaboration with schools. These science communicators are an invaluable resource in the educational landscape and SCRIPT is promoting students' participation in these workshops.

LTS

The Luxembourg Tech School is a non-profit organization that hosts programming lessons that are integrated in the curricula of certain schools as after-school activities. Using the method of the flipped classroom, the IT experts involved in the ITS create videos explaining concepts of managing a project as a group, prototyping and Python coding and guide their students through trimestral projects. These projects are closely linked to industries, such as gaming, finance, banking and the courses collaborate with the respective chambers to provide students with opportunities to present their projects and gather experience in interacting with professionals of these fields.

This initiative started at one campus and catered to upper secondary students of three schools, and now in its third year, has already expanded to 4 campuses and 13 schools. The project is financed and steered by the MENJE's SCRIPT, Ministry of Economy as well as the nationwide Digital Luxembourg government program.

3. Curriculum development

Introduction of ICT in national Curricula

Currently, the introduction of ICT is impacting how students are taught and driving curricular initiatives. At this crucial moment at which a subject is introduced at a large scale, multiple audiences need to be addressed adequately. On the one hand, technical aspects of computer science and informatics are catered to scientific student audiences. On the other hand, computational thinking skills and computer literacy are to be integrated progressively in the collective scientific culture of the school system.

Thus, new specialisation sections are being created for students of the classical secondary schools (ESC) with the aim of fostering future IT and communication professionals. Combining a strong accent on student-centred and creative learning methods with innovative technical content, the section I, for instance, provides new orientation options for students seeking careers in the rapidly developing ICT sector (as illustrated in the second article in this Yearbook from Luxembourg).

So far, computing in classical secondary school is organized in a decentral manner. Schools integrate computing and coding courses as well as activities in their specific course offering. In theory it is conceivable that a student who chooses an informatics section would have his first contact with computing and/or coding after choosing this specialisation. In practise, many subjects use computers and digital tools to develop competencies relative to their subjects. In mathematics courses for example, teachers are encouraged by the national syllabuses to use data tabling software such as Microsoft Excel to solve problems and model data.

In the first three years of vocational secondary school, computing is institutionalised nationally as a course that covers the basics of document editing, presentation and data tabling by means of the Office Suite.

At the time of writing of this article, discussions are being held about the integration of IT in lower secondary education, on one side concerning the technical skills related to office software and more fundamentally the competencies associated with computational thinking and coding.

The integration of computational thinking in national curricula does not limit itself to lower secondary schools but is also being progressively infused in existing primary school subjects. Several pilot projects, coordinated by the SCRIPT, are analysing the efficiency of device-aided methods, such as programmable robots, as well as device-less means of promoting logical and algorithmic thinking. These pilot projects aim at producing insights into the optimal integration of these competencies, testing innovative teaching strategies and developing lesson plans to facilitate broader adoption of these activities.

MathemaTIC

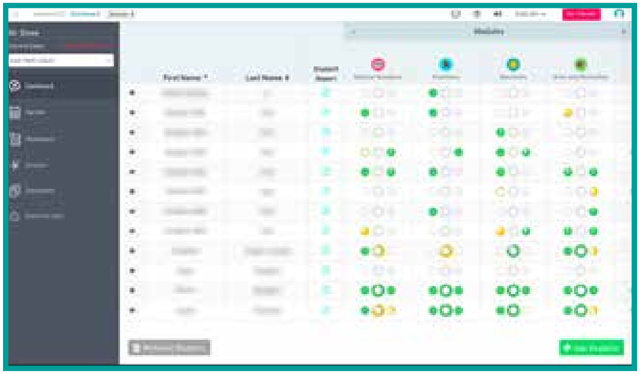
In 2015, as part of the of the MENJE's Digital (4) Education strategy[11], SCRIPT launched the development of the learning software MathemaTIC for students of the primary cycles 3 and 4 as well as the first two years of secondary school.[12]

Through this software, students interact with research-backed, engaging resources that are tailored to their needs and aligned to the learning outcomes as per the curriculum. Diverse resources enable the tailored instruction of mathematics for students and aim at increasing engagement and motivational levels while achieving common goals. Teachers and students are provided real-time academic progress through actionable data. The dashboard allows them to view feedback that directly aligns students' needs with learning outcomes.

[11] MENJE. (2015). Dossier de presse - Digital (4) Education. Retrieved from http://www.men.public.lu/catalogue-publications/themes-transversaux/dossiers-presse/2014-2015/150520-digital-4-education.pdf

[12] See also: CIDREE YEARBOOK 2016, p. 108-119: Amina Kafai-Afif, Jos Bertemes: Low-stakes student assessment for student success: A personalised learning environment in mathematics to raise attainment and tackle inequity.

As the items are not only mapped to topics but also to the curriculum, teachers can gauge how the entire class is doing against the curriculum objectives. Thereby, they can improve and enhance instructional methodologies. However, teachers can also scale down into individual student progress to identify the causes for weakness in performance on specific items or modules.



With a focus on problem-solving skills rather than pure computational skills, the mathematical items have been carefully developed in four languages: German, French, Portuguese and English.

This enables students to understand and work through problems in their native language. The system can also be switched between languages (while working on an item) to enable students to understand the problem in a language other than the language of instruction. It also helps parents assist their children through the learning process.

4. School development

Future Hub label for schools

During this legislative period, schools were granted increased autonomy and were encouraged to develop their own trademark. In the search for ways to provide meaningful STEM experiences, some schools used this opportunity to implement several innovations.

A Future Hub label was created by the SCRIPT to highlight the efforts undertaken by certain schools and to promote these efforts nationally.

In these schools one can find not only new specialisation sections but also a large number of extra-curricular STEM activities, initiatives to promote coding at a lower secondary level and the opportunity to access Makerspaces and participate in Science competitions with the help and support of teachers. These schools combine multiple facets of education to provide a holistic educational landscape to their students where STEM subjects are taught in a formal context while also being accessible on a hands-on basis. These schools place a lot of importance on including student creativity in their lesson plans and take time to foster technical skills as well as passion.

It is within these schools that certain initiatives were incubated and provided a blueprint for the nation-wide distribution. One of these initiatives was the one2one program.

One2one

The one2one program progressively provides each student in Luxembourg with an electronic device. These leased devices are either tablets or laptops and are heavily subsidised by the MENJE. At the end of at least 3 years, the student has the possibility of acquiring ownership of the device for a small residual value. This program has seen many students equipped with tablets and most specialisation courses equipped with laptops. In the years up until 2020, more than half the students in Luxembourg will have been similarly equipped.

By equipping students with digital work environments, it is surmised that computing, as a technical skill, will progressively be integrated into the subjects that use word processors, data tables and presentation software. By acknowledging the omnipresence of digital tools in society and providing the same context to formal education, the importance of coding, algorithms and informatics becomes clearer to students and teachers alike – and opens a lot of possibilities to teachers willing to initiate their students to these skills. Once each student has a device at their disposal, the obstacle of booking a computer room for a given lesson is cleared. Many an algorithm or calculation can be solved in a few minutes on the device, an activity so brief that it would not warrant a class trip to the computer room, yet invaluable as an opportunity to foster computational thinking.

In the last two years, schools have submitted requests for these devices, coupled with a project brief for the implementation of these devices in their schools. These briefs sketch the plan the schools are going to implement technically as well as pedagogically. The SCRIPT guides the schools through the steps of putting together a team to implement the devices, choose their cloud computing system and establish a code of conduct that students should respect when using their tools. The number of devices being requested is steadily increasing and so is the pool of teaching staff that embrace and use these new technologies and attend a evergrowing number of teacher trainings in these fields.

5. Empowering teachers

"[...] being taught by the best teachers can make a real difference in the learning and life outcomes of otherwise similar students. Teachers, in other words, are not interchangeable workers in some sort of industrial assembly line; individual teachers can change lives – and better teachers are crucial to improving the education that schools provide. Improving the effectiveness, efficiency and equity of schooling depends, in large measure, on ensuring that competent people want to work as teachers, that their teaching is of high quality and that high-quality teaching is provided to all students."[13]

Indeed, one of the most important factors in the equation of STEM education, if not the single most important one, is the teacher. Teachers are constantly on the lookout for new learning activities as well as STEM content adapted to their students' age and level of understanding as well as means to update their knowledge with the latest STEM developments and understandings.

[13] *OECD. (2018). Effective Teacher Policies: Insights from PISA. Paris: OECD Publishing.*

Teachers and schools can make a big difference in STEM education by deciding how much emphasis is attributed to learning concepts and facts, observing natural phenomena, conducting experiments, and applying scientific ideas and technologies to understand daily life. It can be a challenge for science teachers or teachers teaching science (for these are not necessarily the same) to find the right balance in stoking interest and improving student performance. The way science is taught could impact students' long-term beliefs about and interest in science.

Establishing strategies and finding a balance between explanation, debate, hands-on activities affect students' attitudes to the subject matter as well as students' performance. Students benefit from teachers who can challenge and captivate their interest, and who combine instructional methods to reach all types of learners.

SciTeach Center

The development of a Resource Center for primary school teachers, in collaboration with the University of Luxembourg provides a focal point, where teachers can benefit from teaching material, instructional methodology and coaching by a team of educational scientists. At the SciTeach Center, hosted on the University Campus, teachers can not only browse through catalogues of material related to the subjects on their curricula, but also benefit from an exhibition space, which lets them explore different scenarios of science education.

Teachers can attend trainings at this resource center to broaden their knowledge of natural sciences. These trainings are accredited by the institute for teacher training (Institut de Formation de l'Éducation Nationale, IFEN) toward their annual quota of mandatory professional development courses.

For those who wish to pursue this interest further, the University also provides a science education certificate representing 30 ECTS targeted at primary school teachers looking to further specialise in this field.

Continued Professional Development

The continued professional development of teachers as well as the teacher initial training program are run by the IFEN, the national institute for teacher training (Institut de Formation de l'Éducation Nationale). This institute is a department of the MENJE and collaborates closely with the other departments.

The number of continued professional development trainings for teachers that are held by the IFEN (Institute for teacher training) in Luxembourg has steadily increased in the last years. The amount of mandatory continued professional development trainings was doubled (from 8 hours per year to 48 hours over 3 years). In fact, the number of hours of training that teachers have followed in average exceeds the minimum required. The programs of these trainings are in line with the policy-making process. In the last two years, an emphasis was placed on digitalisation, teaching and learning languages, establishing school development plans and many other aspects of the secondary school reforms of the last years.

The format of the trainings is widely diversified to respond to the needs of the teachers. Not only are centralized trainings available through an online catalogue and booking system, the IFEN also encourages schools, pedagogical teams and teachers to share and improve their professional practices, through class visits, teacher pairings, thematic networks and specific training schemes requested by schools.

6. Nurturing excellence

Science specialisations in secondary education

The last 4 years in vocational secondary school, respectively the last 3 years in classical secondary school, offer students a choice of specialisation. Among these specialisations, a number are STEM centred:

→ Classical Secondary school:

- ***Section B:*** *mathematics and informatics*
- ***Section C:*** *natural sciences and mathematics*
- ***Section D:*** *economical sciences and mathematics*
- ***Section I:*** *informatics and communication*

→ Vocational Secondary school:

- *Natural sciences section (GSN)*
- *Environmental sciences section (GSE)*
- *Architecture and design and sustainable development section (GA3D)*
- *Informatics section (mathematics, programming, tele-informatics, databases, natural sciences and technology) (GGI)*
- *Engineering Section (GIG)*
- *Heath sciences section (SH)*

It is noteworthy that a large proportion of the sections that prepare students for careers in STEM are relatively recent. These new sections aim to reply to the increased demand for STEM graduates in specialised fields.

Moreover, the distinction between classical and general secondary schools (ESC and ESG) is changing in its nature. These streams of education are still separate but, increasingly, schools are integrating both classical and general classes within their establishments. Subjects, and teachers, that were historically separated, are collaborating more intensely than ever before.

This development has a profound impact on the educational landscape students experience. For instance, classical secondary schools were not able to employ high school teachers specialized in computer science and the few lessons of informatics in classical syllabuses were covered by Math teachers. The same is true for electrotechnical engineers, architects and other vocational professions, who teach subjects that are not in the classical syllabuses. As we know however, the presence of teachers with specialisations like these foster many benefits, such as STEM related afterschool activities, and the interaction with these experts inspire children to develop interests and objectives in these fields.

The cohabitation of both streams, encouraged by the MENJE, fosters the mingling of students in the classical stream with more technically trained personnel. As the classical stream has historically been reserved for the students who attain the best grades in primary school, it is essential to provide this group of students with the proximity to role models in STEM fields.

Science Olympiads

A tenet of science culture in Luxembourg is the participation in national and internaional science Olympiads and contests, which allow students in secondary school to pit their minds against questions and brainteasers on a subject in a competitive arena. Often these Science Olympiads look for students who solve problems creatively and show a passion for these subjects that transcends simple reproduction. A large part of the organisers' contribution is the effort they put into training promising candidates over the length of a few years and grooming them for international competitions. Even though these Olympiads are competitive and only a handful of students make it to the international contests, their visibility in schools is high. Many students of all ages participate regularly, and the winners do enjoy a certain well-deserved publicity in their schools.

Low percentage of STEM orientation choices - high percentage of success in degree completion

In the Classical Secondary Schools, the B section, especially in combination with the Latin studies, is commonly handled as the cream of the crop. Having passed through secondary school with high multilingual standards, these students also excel in mathematics and sciences. They invest a large amount of time in the honing of their language skills and attribute an equal amount of time to acquiring mathematical fundamentals such as functional analysis (derivation, integration) as well as probabilities and statistics. In physics they acquire a theoretical background in Newton's laws of dynamics, waves and oscillations as well as a brief introduction to modern physics (theory of relativity and nuclear physics). In chemistry they learn about the atomic models, acid and alkali properties and the basics of organic chemistry.

Indeed, as supported by the data gathered by the CEDIES (Centre de Documentation et d'Information sur l'Enseignement Supérieur), the national agency that documents and provides information related to higher studies, the students who do choose to pursue scientific degrees upon completion of B and C sections are well prepared for the university courses that await them in the European Universities they choose. They pass the filtering of students through tough mathematics courses in France and Belgium, pass the orientation tests in the first year of German and Austrian courses and can switch universities easily when their specialisation calls for it due to their fluency in many languages.

Indeed, one would think that all but a few of the students who choose and graduate from this specialisation section in secondary school would end up as successful STEM professionals.

However, students from this section do not consistently pursue scientific degrees. In fact, when considering the choices made by students passing the final exam, a considerable proportion select subjects of different fields.

While one should certainly not pressure individual students to follow STEM studies if they decide to orient themselves in other directions, as an education system, it is important to understand why students being specifically groomed for these degrees are making their final choices towards other fields.

One may distinguish three possible scenarios for students who choose non-scientific degrees after graduating from this scientific section:

- *Students choose this section for different reasons, knowing that they will not specialise in this field. Possible reasons may be*
  - *Prestige of the section*
  - *They feel the need for a strong mathematical background*
- *Students who were undecided but qualified were more attracted to a non-scientific degree during the three years of scientific specialisation studies*
- *Students who were planning to pursue scientific degrees loose interest in this field during the three years of specialisation studies*

While the first possibility does not seem problematic, it would be worrisome if the second and third were common occurrences. Are the selling-points of scientific careers not being communicated well enough? Are the courses too hard? Are students being encouraged to identify themselves with the subject matter or do they just regurgitate what they have learnt by heart?

Especially when students from these fields choose language studies, arts or humanities, one may wonder if the students feel that these domains offer them more chance of self-realisation than scientific fields. Indeed, students are prone to thinking that these subjects allow them more room for expression and debate, factors that appeal greatly to teenagers. Literature is rife with romanticised authors and influential poets, and the humanities seem to promise a greater understanding of the meaning of life itself. In affluent societies, especially in the western world, very few students idolize scientists. Should it be a part of the scientific sections' objectives to promote the appeal of science or is it enough to instruct students in theoretical knowledge?

The juxtaposition of a high success rate among those who do pursue scientific studies and the low rate of orientation towards these studies poses a conundrum. One may argue that the approach taken in these sections is successful in preparing students for their degrees. However, it could also be debated that the students who excel in languages and mathematics are simply excellent by their own merit and would succeed no matter how the subject matter were taught. In this case, the sections should dedicate themselves increasingly towards motivating undecided students to commit to scientific studies.

This question is one that can be extrapolated to all levels of science education: should we conceive science education as a credential to provide an elite the access to scientific degrees or as a broader vessel of scientific culture that may sometimes trade rigour for appeal?

Scientific Elites *vs.* Scientific Culture

When considering the question if science education should be geared towards the elite or the broad, it is worthwhile to look at the approach taken by language education. Every student follows the same language courses and yet some pursue literature while others acquire the language up to a certain proficiency level.

Most languages have multiple implementation levels, such as slang, casual, spoken, formal or literary. Languages also transit fluently from one level of implementation to another. If an author decides to artfully include slang in his new novel, it may even contribute to his success.

The sciences however do not easily deal with variations from the canon. Even valid scientific innovations and revolutions first engender scepticism – if not rigorously proven, scientific statements are usually void.

The only mode of communication that written science generally accepts is a formal language and students are penalised for straying from conventions and notations. The occasions where students contribute original answers are so rare that they are retold as anecdotes of great mathematicians and scientists, as in: "When Euler's teacher asked him to calculate the sum of the numbers from one to hundred he found an easy way to do it, that even his teacher did not know."

Language teachers asking students to write an essay about their holidays support the students in expressing their story in a more efficient manner. Science teachers are often in the situation where they instruct students to recreate one and the same answer, one that the teacher already knows.

It is of course beneficial to let students who thrive in scientific rigorousness acquire these skills and pursue classical scientific studies and move on to contribute to these fields at an expert level. At the same time, more students may be attracted to science if their creativity is valued and central to the teaching of scientific content. Many a lesson may be lost to "wrong" ideas and "useless" experiments, but then again, most literary essays written in secondary school are far from a thrilling read. It is indeed the discussion surrounding the students' forays that are of utmost value and provide great learning opportunities.

One way of resolving this duality is by splitting science education in two age groups: common core years and specialisation years, such as it is the case in Luxembourg. Another would be to create fundamental and advanced study groups, a concept that has been advanced and is currently being implemented in Luxembourg in language teaching.

Both methods have their potential disadvantages: Teachers in the first four years of secondary school start preparing the students for the specialisation sections, anticipating which skills they will need and transforming the common core to a pre-specialisation course. By splitting the groups, it is all too easy to condemn a student, as well as his self-appreciation in a given domain, to the second tier. Once the groups are defined, a student from the second group must invest a lot of effort to get propelled to the advanced group, and in the meanwhile will have missed certain topics which his new study mates have already completed.

As of today, we need to double down on providing our STEM elite more opportunities to exercise their creative potential in scientific fields. As we will see in the following sections, creativity and student-centred learning are increasingly encouraged in the curricula of the new sections as well as in extracurricular activities. These initiatives aim at increasing the rate of students that pursue scientific studies after graduation.

Also, considering the skills needed by the broader population in a world run by numerical data, farranging initiatives are being undertaken by the MENJE to promote scientific culture throughout the Luxembourgish schools and society.

Conclusion

The challenge of making STEM careers more attractive to students while maintaining and improving the performance of students in science competencies could be achieved by taking a holistic approach to science education. Students need to be introduced to STEM activities early on while focussing on developing their ambitions and attitudes toward these subjects. Enquiry-based and student-centered learning coupled with exposure to the many semi-formal and informal opportunities for STEM learning should illustrate to students, teachers and parents alike that STEM subjects are an intrinsic part of Luxembourg society and culture.

It is essential to develop the transition from this early stage of STEM education toward a more rigorous scientific course: students should understand the need for these formalisations through the beliefs about science developed in primary school. Many initiatives exist to this effect and as an administration it is our duty to oversee that the insights gained through punctual activities are nurtured and deployed to the benefit of students throughout the country.

The willingness of primary and secondary schools to collaborate on these matters in orientation programs countrywide show that these partnerships can develop to foster a mutual science education approach.

The coherence of curricula in general will contribute in a large part to the credibility of science subjects. If students are encouraged to enquire about phenomena, mathematics, physics and chemistry, teachers will benefit from common approaches and well-defined curricula, allowing them to answer students' questions and guide their experiments with a concerted strategy. Though there are many positive developments in this direction, this challenge will continue to be relevant as more specialisation streams are created. As science knowledge and relevance develops rapidly, due to new technologies and new careers, the classical STEM subjects will adapt their curricula and emphasis more regularly than in previous eras.

We see that teachers in primary schools are looking for ways to acquire more specialized science education competencies and science teachers are redefining their roles to include more promotion of their subjects through everyday applications and modern tools that are integrated in the classroom. Globally, new technologies help teachers achieve this by facilitating visual displays, experimental procedures and allowing students to experience science in a more hands-on fashion.

It is encouraging to see that a large network of volunteers, educators, teachers in their free time, researchers and science professionals are eager to participate in the conversation around science education. By highlighting these resources to teachers and students alike, a diverse landscape of learning opportunities opens in front of students, and hopefully each student will be able to develop a relationship with science free of fear or misunderstanding, one that will benefit them in their future, either in a scientific career or in all other endeavours.

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Authors

Bob Fisch

Bob Fisch studied at the « Superior Institute of Technology” in Luxembourg to become an industrial engineer in applied informatics and then completed his studies with a DEA (Bac + 5) in bio-informatics at the University of Le Havre.

In 2004, he started teaching at Lycée des Arts et Métiers, and in 2007, he successfully completed his teacher education course. Since 2008, he has developed a large number of management applications for the school, helping to automate repetitive tasks and to simplify administrative processes. In 2010, he helped set up the BTS in informatics (Bac+2 higher-education course), and he actively participated in launching the section “Informatics and Communication” in 2017. Most recently, he led the team in charge of establishing the BTS “Internet of Things” set out to start in September 2018.

Serge Schaetzel

Born in 1978, Serge Schaetzel completed his primary and secondary education in Luxembourg, receiving his school-leaving diploma of the classical stream, mathematics section, in 1997. Next, he took the first year of a bachelor’s degree in mathematics at the University of Luxembourg, and completed his degree in 1997 and 1998 at the University of Brussels (ULB). From 1999-2001, he studied for his master’s degree at the ULB, specialising in analysis.

In 2001, he passed the recruitment examination for the teacher education programme in mathematics in Luxembourg. From 2001 until 2003, he successfully completed his teacher education course in Luxembourg, and became a newly-qualified teacher (professeur candidat) in 2003. In 2004, he wrote his thesis (travail de candidature) on problem-solving in secondary education in the context of the PISA study. In 2005, he was appointed a teaching position at Lycée des Arts et Métiers in Luxembourg, where he still teaches today.

Authors

Kim Heuskin

Kim Heuskin completed her secondary education in Luxembourg in 2003 with a school-leaving diploma focusing on modern languages. From 2003 until 2004, she completed a certificate of literary and linguistic studies at the University of Luxembourg. She studied English and American Literature (BA, Hons) at the University of Kent from 2004-2007, and then obtained a Master's Degree in Postcolonial Studies from the same institution in 2008. From 2008-2011, she completed her teacher education at Lycée Classique Diekirch in Luxembourg, and was then appointed as a newly-qualified teacher (professeur candidat) at Lycée des Arts et Métiers in 2011, where she has taught English as a foreign language since. In 2012, she wrote her thesis (travail de candidature) on cultural contents in English language coursebooks used in Luxembourg.

Abstract

The article on the new “Informatics and Communication course” in the classical stream of Luxembourg’s secondary education system briefly describes the context in which the country’s Ministry of Education, Childhood and Youth introduced an additional specialisation stream for students in years 11-13. Next, some information is provided on how ICT and modern teaching and learning methods were integrated into the course right from the start. Subsequently, the article outlines the course-specific subjects with their respective aims and objectives, their methodologies and a brief overview of contents. Particular attention is given to the “Project Management” course due to its innovative and interdisciplinary set-up. The final part of the article is devoted to a detailed analysis of how ICT and a more forward-thinking methodology were implemented in a general subject, mathematics in this case. There are a number of specific examples to illustrate how “conventional” topics of the syllabus have been approached using modern applications such as GeoGebra, Photomath or Wolfram Alpha to provide learners with more interactive, effective as well as motivating learning experiences.

Informatics and Communication Section – Section I ESC – Luxembourg

Introduction

This article intends to describe and analyse the new Informatics and Communication course (section I – informatique et communication) created in 2017 for the classical stream of the secondary education system (enseignement secondaire Classique) in Luxembourg. The course was created based on a need to train future digital leaders in Luxembourg, and due to the fact that the classical stream in Luxembourg did not yet offer an IT and communication course to students at that point. Particularly in the context of the Digital Luxembourg initiative, which aims at fostering digitalization at many levels as a "tool for positive transformation", it became evident that such a course was required to further develop the offer in Luxembourg's secondary education system and to meet the future requirements of a digital society.

In fact, IT courses are offered in Luxembourg at many different educational levels, be it in vocational training, in the general technical stream, or at BTS level (a two-year higher education course), but there was no equivalent offer for students of the classical stream until the introduction of the section in 2017.

At the start, the new informatics and communication option was offered in two secondary schools in Luxembourg (Lycée des Arts et Métiers in Luxembourg City, and Lycée Guillaume Kroll, formerly Lycée Technique d'Esch-sur-Alzette, in the south of the country), both owners of the Future Hub label identifying innovative schools that have already manifested an openness to technological developments, and a readiness to implement modern technologies in the learning and the teaching process. The label also implies a holistic integration of sciences and STEM education in the curriculum, as well as in extra-curricular activities on offer. From September 2018 onwards, the course will also be taught in a third school, Lycée Edward Steichen in Clervaux, to provide a countrywide offer for students in Luxembourg.

The informatics and communication specialisation option (section I) covers three years, from year 11 to year 13, after which students graduate with a high-school-leaving diploma, which provides access to university courses in Luxembourg and abroad. Students therefore require a solid grounding in the basics such as foreign languages (German, French and English), mathematics, and sciences, as well as in subjects such as history and ethics. In addition, course-specific subjects include programming classes, an introduction to modern technologies, a graphics design class, a media communication class and, in years 12 and 13, a course on financial economics and data management. Alongside these subjects, an interdisciplinary course aimed at developing entrepreneurial and project management skills represents a core subject for learners over the three years: Projet Management.

Appendix 1 provides a detailed overview of the different subjects taught in the informatics and communication section.

Due to the innovative approach of this new section, students do a large amount of project-based learning intended to foster learning autonomy, creativity and responsibility, making use of the flipped classroom method for instance, and resorting to online learning platforms such as eduMoodle. Furthermore, the schools that offer these courses have aimed at introducing alternative seating arrangements in the classroom to further encourage forward-thinking learning and teaching approaches and methodologies.

Integration of information technology

Given the fact that this new informatics course was intended to foster IT skills right from the start, students were equipped with individual devices in a "one2one" programme that provided them with laptop or tablet PCs featuring all the required software for all the subjects. To guarantee equal opportunities for success, the participating schools, in collaboration with the government's IT management centre for education (CGIE), provided the students within a school with identical devices with a rental contract.

The use of these personal computers, laptops and tablet PCs is promoted in every course and subject, though digital devices are not used exclusively in all learning activities. In fact, paper books and notebooks are still required since not every task can be done online or digitally. Except for the IT-related courses, the computers are thus mainly used as communication devices: tasks and additional hand-outs are no longer photocopied but shared via a learning management system. The same applies to homework and other assignments: students tend to upload their work rather than hand in print-outs or handwritten productions. It is important to mention that the classes are not entirely paperless, as a digital option can at times be more time-consuming and/or complicated. While some students opt to take notes in a digital form, others may still choose to jot down key ideas on a paper notepad. Conversely, some teachers may prefer to note down certain additional explanations on the blackboard or whiteboard to save time. In addition, summative tests in more general subjects (languages, mathematics, etc.) are mostly still done on paper, whereas certain formative tests or progress checks might already be done using an online learning platform or quiz website.

In general, in most courses, the theoretical elements are taught in ways that keep practical fields of application in mind, which helps students to consolidate their knowledge and tends to simplify overall learning processes. Teacher-fronted lessons are to be avoided in favour of methodologies such as “blended learning”, “flipped classroom”, or “task-based” or “problem-based learning”. One must bear in mind though that a majority of students in the Luxembourg educational system are not necessarily accustomed to being very active learners, and therefore, the process of involving students more in their learning processes needs to be gradual, especially in year 11. Fostering learning responsibility and autonomy, especially with regard to acceptable uses of digital media in class, is thus one key element that is developed from the start, and this in every subject.

Course-specific subjects

Programming

One of the specific classes offered in the informatics and communication section is a programming course in which students are taught the basics of a programming language and learn how to code common algorithms. Students use Java as a programming language in a learning environment designed to foster their problem-solving skills and creativity. When planning, implementing, testing and debugging applications, students are led to apply their skills to issues provided in the context of a problem-based learning approach intended to encourage critical thinking processes and creative solutions.

Technologies and Innovations

In the subject entitled “Technologies and Innovations”, students do not only learn how computers and networks work, but they also encounter more recent technologies such as artificial intelligence, micro-controller programming or the Internet of Things. Students are encouraged to research, analyse and contextualise technological developments and to tackle complex tasks while trying to find adequate IT-related solutions.

Data Analysis and Management

The “Data Analysis and Management” course aims at introducing learners to ways of collecting data, and storing it in a structured manner, as well as ways to exploit it, all in the context of shaping the minds of future digital leaders. In the light of the big data debate, students are introduced to the socio-economic impact of data collection, management and security, while broaching legal, ethical and organisational issues. These rather complex ideas are conveyed in authentic learning situations that ask students to identify the requirements of a given situation and to develop appropriate data management structures.

Media Communication

In the media communication course, students learn to communicate effectively using different communication channels: orally, textually, or visually, partly using both traditional media like the radio, but especially focusing on new and modern digital ways of spreading messages. There is a particular focus on the impact of social media on traditional media outlets and on the social, political and cultural repercussions of the former. In addition, students are introduced to ways of researching, processing and presenting information for the different channels of new technologies.

Project Management

Another crucial part of the curriculum is the interdisciplinary project management course in which students learn how to handle projects, starting out with small specific tasks during which a lot of scaffolding is provided, and ultimately culminating in rather complex projects that the students are expected to manage rather autonomously. One of the particularities of this subject is that it was developed for team-teaching, which, in this case, implies that three different teachers, from different subjects, accompany the students. These same teachers define a common set topic, or challenge, which provides the background for the students to define their individual project. One overall topic was “environment”, for instance, which allowed students to opt for a project such as “the speaking trash can” (i.e. a rubbish bin that says: “thank you” each time anyone throws something away), or an “anti-rotting box” which slows down the decomposition process to keep fruit fresh for longer.

One of the main goals of the project management course is to make students aware of the fact that the more theoretical and abstract elements they encounter in other classes also have practical fields of application. Consequently, the teachers assigned to this course seek to choose topics that can be easily connected to the official syllabus of their own subject, and the overall curriculum. Teachers of subjects that are not directly connected to the project management course are nonetheless invited and encouraged to adapt their course from time to time in order to incorporate the project management topic into their own classes and subject.

When realising their project in the context of the topic or challenge provided, students are required to complete several tasks related to project management, namely identifying the requirements and specifications associated with their task, establishing a financial plan, providing specifications for potential products, coordinating processes and resources, meeting deadlines, etc.

Best practice example: Mathematics

Overall context

Given the shortage of qualified and well-trained professionals in the domain of ICT, the new informatics and communication course has the purpose to train students with a scientific profile. This is also the reason why information science, programming and mathematics play a prominent role with five weekly lessons of mathematics in years 11 and 12, and six lessons per week in year 13.

Methodology

Most classes are taught based on the “flipped classroom” concept, using learning materials made available by the Khan Academy platform, and complemented by additional support materials created by the teacher. New topics are introduced using activities that allow learners to discover mathematics, while new technologies are consequently employed in order to lessen the amount of repetitive calculations and to gain time to deal with more complex exercises, whether at the level of understanding or at a technical level of the calculations.

Mathematical syllabus and tools

Regarding content, the mathematics syllabus in the informatics and communication section is largely identical to the one used in the natural sciences section of the classical stream in Luxembourg, although the methodology is considerably different. One reason behind this similarity is, on the one hand, to allow learners to pass from a year 11 informatics section class to a year 12 natural sciences class without any major difficulties. In fact, the lack of possibilities for students to switch between sections was a major critique expressed by the PISA study with regard to the Luxembourg school system, and the similarity in mathematics in year 11 was therefore created intentionally to facilitate a passage of learners who wish to change their learning foci. On the other hand, the mathematics syllabus in the natural sciences section, and conversely, the informatics-based one, is aimed at preparing students for university studies in scientific subjects.

The syllabus includes the following topics and elements:

- *Functions: definitions, variations, extrema, roots, parity, elementary functions, (in particular those of the first and second degree), and graphical manipulations. All of these are done without derivatives, which are introduced in year 12. Overall, functions are a vast subject for which new technologies are consequently applied, be it by using with GeoGebra to trace curves, Wolfram Alpha to get a complete analysis of a function, or Photomath to verify intermediate calculations.*
- *Numerical sequences, with a particular focus on arithmetic and geometric sequences, and the method of demonstration by recurrence. This chapter represents the biggest difference to the syllabus of year 11 of the natural sciences section because a solid understanding of the method of demonstration by recurrence is particularly important for loop programming processes. Regarding sequences defined by functions, the ICT tools used are of course the same as for functions; for sequences defined by recurrence, we use the spreadsheet application Excel. For the exercises on demonstrations by recurrence, we have created videos which the students can resort to if they encounter issues when resolving problems in order to allow every student to work at their own rhythm and to differentiate accordingly among individual learners.*
- *Probability: the notion of random experiences, calculations of sets and possible results, the probability of simple events, (independent, complementary and impossible), the use of different diagrams (tree diagrams, etc.). For this chapter, we used GeoGebra to program a random experience based on the Monte-Carlo method to approximate π.*
- *Straight lines, director and normal vectors, Cartesian equations, common linear equations, parallel and perpendicular straight lines, equations systems and inequality. We have used GeoGebra extensively to graphically represent straight lines, interpret different coefficients of an equation of a straight line, graphically resolving systems of equations, inequality and resolving problems of optimisation connected to these systems.*
- *Trigonometry in the trigonometric circle, cosine or sinus theorems: we have used GeoGebra for the visualization of trigonometry in the trigonometric circle, of the resolution of trigonometric equations, and the values of functions of the trigonometric circle and graphic manipulations of the latter. For sinus and cosine theorems, we used the resources made available by Khan Academy to differentiate the learning process.*

Precise examples

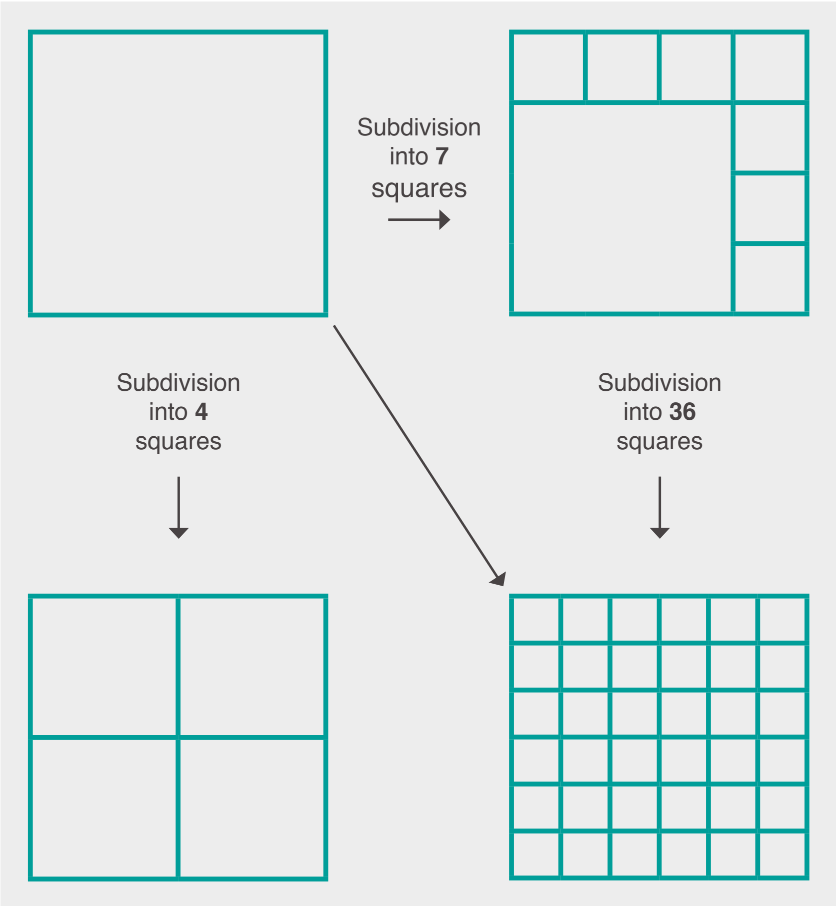
- ***Recurrence:*** *an introductory activity*

– *A square can be subdivided into smaller squares:*

Question:

What are the numbers for which such a subdivision is possible? Impossible? Justify your answers!

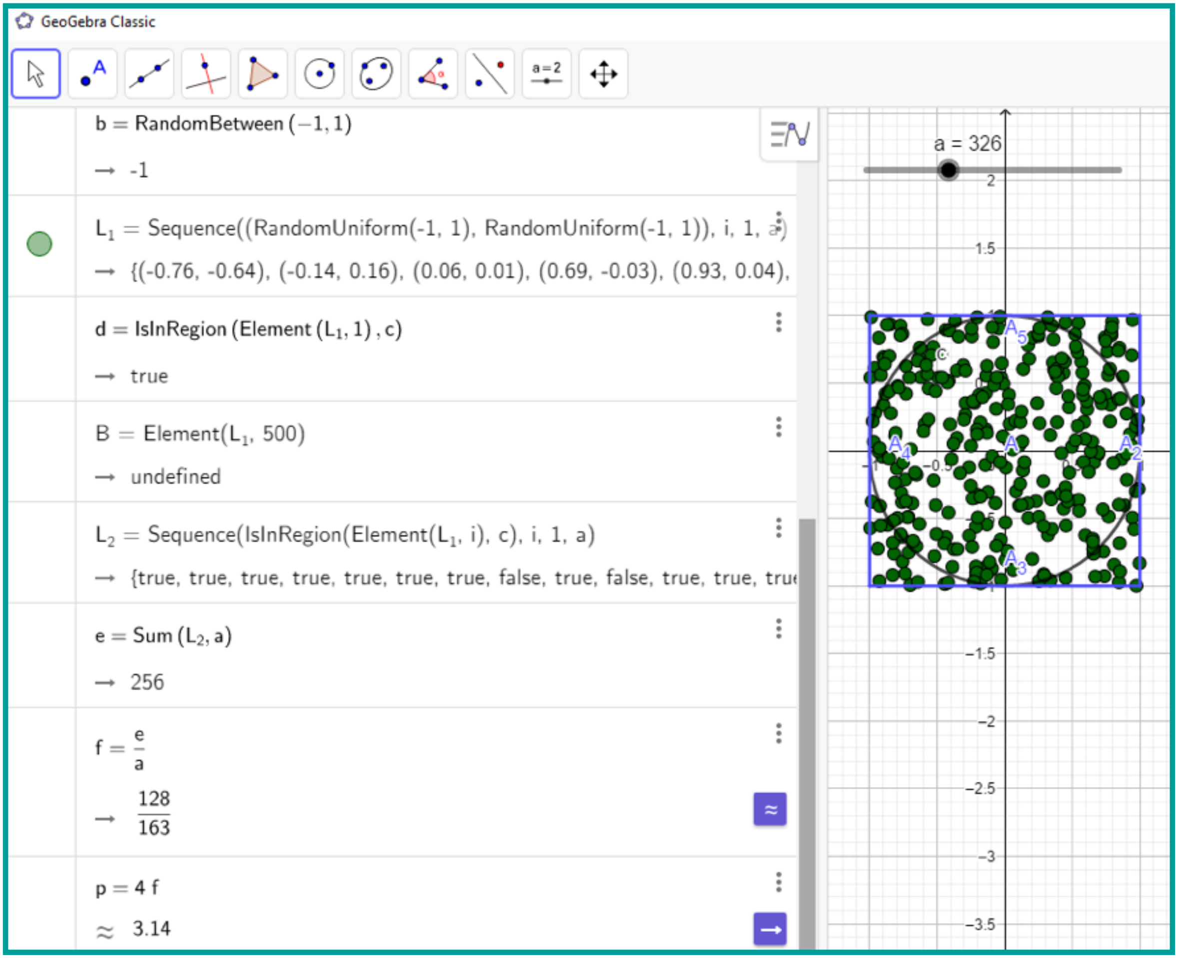
This activity has one main advantage because learners of any level can easily, and rapidly, start their research. Moreover, every student is likely to find at least one partial result. The idea for the resolution is that by dividing a square into four, one obtains from one solution another one with three additional squares. By thus finding one subdivision with three consecutive numbers (6, 7 and 8 in this case), one demonstrates by recurrence that all the following numbers are possible.



- ***Probability:*** *the Monte-Carlo method and an approximation of π*

The idea of this task is to use GeoGebra to randomly generate dots in a square in which a circle is fitted. Counting the dots in the circle and comparing the surface of the two geometrical forms, one can find an approximate probability of π≈4 (number of dots in the the circle)/(number of dots in the square).

This task thus allows for an illustration of the law of big numbers by using programming in GeoGebra (see figure below ↓).



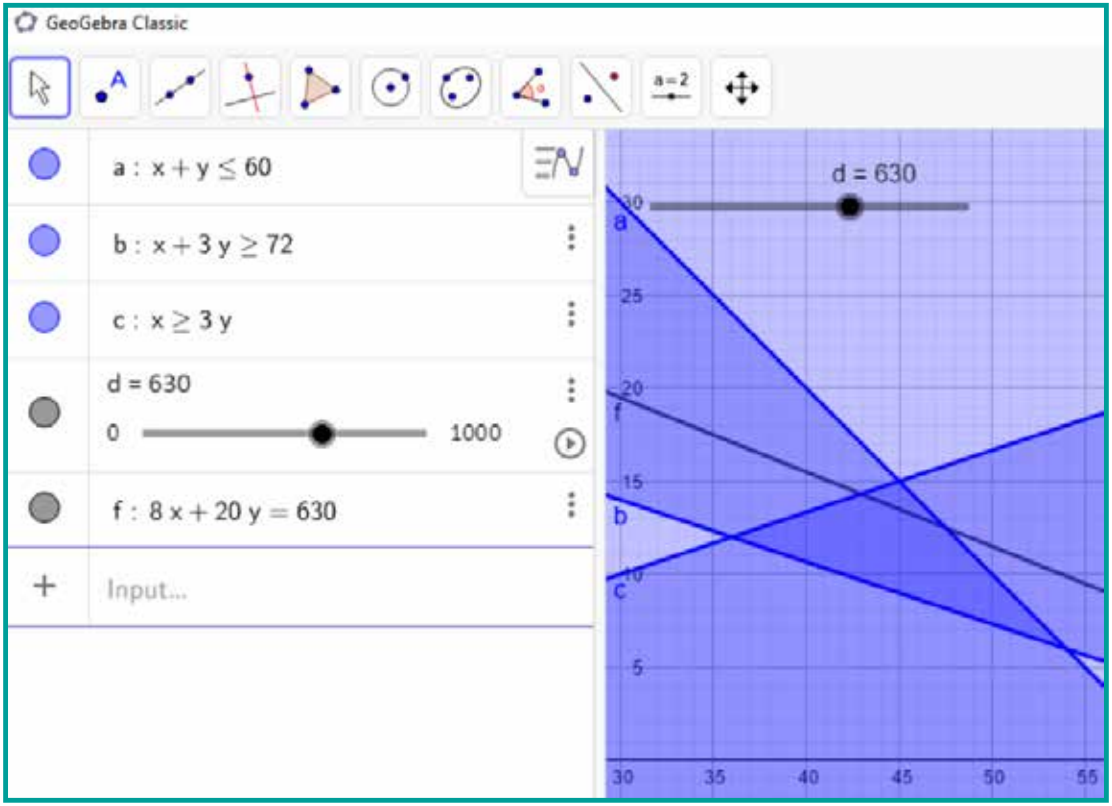
- ***Systems of inequations:*** *optimisation problem ↓*

Question:

every year, an amateur winegrower produces white wine which he sells to his friends. He uses two types of bottles: bottles of 1l and bottles of 3l. This year, he will produce at least 72l of wine. In the past, he noticed that bottles of 1l are demanded at least three times as often as those of 3l. However, he does not want to go above 60 bottles. He sells the bottles of 1l at 8 € and those of 3l at 20 €. How many bottles of each size does he have to produce to maximise his profit?

Other than the fact of having to translate this problem into a system of equations easily presentable in GeoGebra, the search for an optimal solution is simplified in this case by the implementation of a slider called profit, d in the image above, which allows to dynamically represent the straight line associated with the profit equated by 8x+20y=d.

The students thus still need to research the maximum value of d for which there is a point of entire coordinates situated in the region limited by the system of inequations and which can be found on the straight line associated with the profit.



- ***Trigonometry:*** *the passage of a trigonometric circle with a sinus function* ↓

Question: *in GeoGebra*

1. *Define a slider of values between 0 and 720. It represents the angle α in degrees and will be called a by GeoGebra.*
2. *Define a sequence containing a points with the respective coordinates (cos(i°), sin(i°)), i taking the values of 0 to a.*

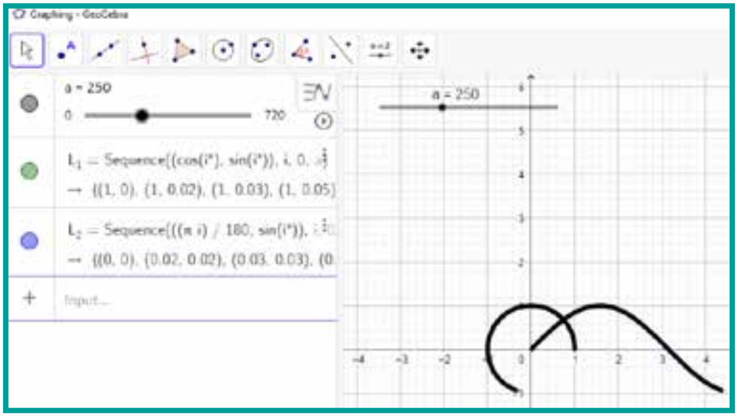
   When moving the slider, one notices that GeoGebra then draws a large number of points of the trigonometric circle.
3. *One would now like to trace the function f(x)=sin(x), where x is given in radians.*

   a) *What is the relation between x and i?*

   b) *What are the coordinates of the abscissa x of f? (____ , ________)*

   c) *Define a list containing a coordinate points (πi/180,sin(i°)), i taking the values of 0 to a.*
4. *Modify your exercise to trace the functions cosx and tanx.*

The chapter on the trigonometric circle is generally rather abstract and GeoGebra thus allows learners to consolidate their knowledge about the trigonometric circle and the trigonometric functions in a more practical manner. This also makes the lesson less abstract and monotonous.



Conclusion

Given the recent introduction of the new informatics and communication specialisation stream, it is currently difficult to make predictions about its success, though current enrolment statistics suggest a positive trend. One can assume that this is partly due to the demand among learners and parents for a course that focuses on the technologies of the future; moreover, the more modern and innovative methodological approach to learning and teaching certainly also appeals to many students as it allows for greater autonomy and creativity.

Appendix 1

TEACHING SYLLABUS (YEARS 11-13, number of lessons per subject, per week)

[1] Students of the CLI classes also take Latin as a subject.

[2] Students choose either French or German in their final year, English is compulsory.

[3] Students choose one of the two languages chosen in year 12.

[4] Programming is a core subject (i.e. an insufficient mark in this subject cannot be compensated; students with insufficient results in this subject must pass an additional resit examination before they may continue)

Subject	3CI (year 11)	2CI (year 12)	1CI (year 13)	3CLI[1] (year 11)	2CLI (year 12)	1CLI (year 13)
French	3	3	3[2]	2	3	3[3]
German	3	3		2	3	
Latin				3		
English	4	3	3	4	3	3
Mathematics	5	5	6	5	5	6
Programming[4]	2	2	3	2	2	3
Technology and innovation	1	2	2	1	2	2
Data analysis and management		2	2		2	2
Media communication	1	2	2	1	2	2
Project management	1	2	2	1	2	2
Chemistry	1.5			1		
Physics	2.5	3	3	2	3	
History	2	1	1	2	1	1
Biology	2			2		
Graphic Design	1			1		
Ethics	1			1		
Civics		1			1	
Philosophy			2			2
Financial economics		1	1		1	1
Physical education	1	1	1	1	1	1
Total	**31**	**31**	**31**	**31**	**31**	**31**

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SCOTLAND

Author

Ian Menzies

Ian Menzies is a Senior Education Officer within Education Scotland, the Executive Agency of the Scottish Government responsible for quality and improvement in Scottish Education. In his early career as a secondary physics and mathematics teacher, Ian taught in Zambia and Malawi as well as in Scotland. He is now responsible for supporting the national science curriculum for 3 to 18-year olds and has been closely involved in developing Scotland's new STEM Education and Training Strategy.

Ian leads the Advancing Equality Workstream within Education Scotland's Developing Young Workforce (DYW) Programme. This programme seeks to tackle youth unemployment in Scotland by better preparing young people for the world of work, especially those young people who face barriers to employment due to gender, disabilities, race or institutionalized care. He is now responsible for Education Scotland's Learning for Sustainability program which includes education for sustainable development, outdoor learning and global citizenship education.

Abstract

The Scottish Government launched its STEM Education and Training Strategy in October 2017. The five-year strategy sets out an ambitious agenda to make Scotland a 'STEM nation' by transforming STEM provision across all sectors including early learning and childcare, schools, colleges, universities and community learning and development settings. The strategy is closely aligned to a process of significant reform in Scottish education which aims to promote excellence and equity through raising attainment and increasing positive post-school destinations, especially for learners from our most deprived communities. Under the themes of Connection and Inspiration the strategy seeks to promote more efficient cross-sector working and spark engagement in STEM and pursuit of STEM-related careers.

This article explores the journey that led the Scottish Government to develop its STEM Education and Training Strategy and describes its alignment with other key policy areas. It sets out the rationale and ambitions of the key themes in the strategy and how these will address key challenges such as teacher recruitment in STEM subjects, provision of professional learning for practitioners, improving gender balance and equality, and the development of new STEM learner pathways to tackle youth unemployment.

Introduction

"This strategy sets out our vision of a Scotland where everyone is encouraged and supported to develop their STEM capability throughout their lives, enabling them to be inquiring, productive and innovative, both in order to grow STEM literacy in society and to drive inclusive economic growth… it is designed to drive improvement in relation to STEM and ensure co-ordinated and focused action right across the education, training and skills landscape in Scotland."

Shirley-Anne Somerville MSP, Minister for Further Education, Higher Education and Science
STEM Education and Training Strategy for Scotland, 2017 (Page 2)

The Scots are rightly proud of their rich heritage in science and STEM and of the significant contribution their small country has made to the world. Stop anyone on the street and they'll be able to recount a long list of Scottish achievements from the invention of the TV and telephone to the pneumatic tyre, logarithms and Dolly the sheep, the first cloned mammal.

However, as the mighty industries that fuelled Scotland's industrial revolution have declined, our nation has had to look to new STEM-related sectors and industries to ensure future growth and prosperity for its citizens. The leviathans of our industrial economy: shipbuilding, coal-mining and steel, are now being replaced by 21st century sectors such as life sciences, food and drink technologies, digital and creative industries, low carbon technologies and the circular economy[1].

Scotland's new STEM Education and Training Strategy, launched on 27 October 2017, sets out an ambitious and bold plan of action to facilitate this transformation through STEM education. As we realise our goals we will ensure that:

- *our population will be able to thrive in an increasingly scientific and technological world and will benefit from enhancements in health, environment and quality of life that STEM innovation brings*
- *our industries will have the highly-qualified, skilled and motivated workforce they need to continue to grow and to support our economy*
- *our country will be able to tackle child poverty, social inequity and the generational unemployment that has blighted many of our communities.*

This article explores the context which has led Scotland to develop its National STEM Education and Training Strategy. The article will detail the challenges that we face and how we are seeking to address this by promoting excellence, equity, connection and inspiration in STEM.

A number of European countries, including the Republic of Ireland and the Dutch and Flemish Governments, have also launched national STEM strategies to address similar issues and challenges. Pan-European networks, such as CIDREE (Consortium of Institutions for Development and Research in Education in Europe), have played an important role in creating opportunities for European member organisations to come together to share approaches, practice and strategies relating to STEM. The EU STEM Coalition[2], launched in 2015 and supported by the European Union, aims to bridge the STEM skills gap by ensuring that all EU member states have developed national strategies for promoting STEM disciplines.

[1] *Making Things Last – A Circular Economy Strategy for Scotland: http://www.gov.scot/Publications/2016/02/1761*

It is hoped, therefore, that this article will contribute to the wider discourse about STEM skills and education within the European and global context.

Preparing the ground

In 2013, it became clear to Education Scotland that the profile and engagement of interdisciplinary approaches to STEM were increasing in a number of local authorities across Scotland. This was in contrast to the strong focus that schools and practitioners placed on the individual curriculum areas of science, technology and mathematics as they introduced Scotland's new curriculum, Curriculum for Excellence in 2009.

Schools began to approach Education Scotland more frequently for advice and guidance on their STEM activities. At the same time, many external providers and partner agencies were contacting Education Scotland for guidance on how to engage with schools in STEM or to establish pilots or other programmes of activity.

Rather than lead a range of disparate pilot programmes, Education Scotland set up a strategic new programme called The National STEM Project. The aim of the programme was to develop effective approaches to STEM within school cluster groups. A cluster group comprises a secondary school (providing six years of education for 12-18 year olds) and its associated primary schools (providing seven years of education from 5 to 11 years) and early learning and childcare establishments (providing education for 3 to 5 year olds, and sometimes from aged 2).

[2] *EU STEM Coalition: http://www.stemcoalition.eu/*

[3] *The Wood Foundation: https://www.thewoodfoundation.org.uk/*

Five school clusters across four local authorities were invited to participate in the programme over an 18 to 24 month period. This involved a total of about 50 establishments. Various inputs were provided including training and networking events which brought all the clusters together to support their self-evaluation and to share practice and approaches.

A key principle of this approach was to focus resources and support on these school clusters to see how various interventions and programmes interacted with one another and what the collective impact would be. A range of different activities and pilots developed by various STEM agencies and providers, including industry and colleges, were trialled. These included programmes to promote partnership working with employers, tackle gender stereotypes and to promote digital learning and parental engagement in STEM programmes.

The National STEM Project provided a valuable test-bed for many different approaches and provided a rich seam of learning in terms of the effective implementation of STEM within and across different sectors. A review of the programme was conducted in 2017/18 and helped to inform the development of the National STEM Education and Training Strategy. Some of the clusters and establishments involved have achieved regional and national recognition in terms of their STEM approaches and have played a valuable role in sharing their practice with others.

As important as the National STEM Project was, however, a pilot involving five school clusters is still some way from a coherent national approach that would prove effective across the three hundred and sixty secondary school clusters in Scotland. These school clusters often operate in very different local contexts, in terms of demographics, socio-economic factors, industry needs and rurality.

An emerging partnership with The Wood Foundation[3] in 2016 provided a further valuable opportunity to build on the achievements of The National STEM Project and scale these up to benefit a wider number of authorities. The Wood Foundation committed £1 million GBP (1,148,000 Euros) to a 33-month pilot to develop science and STEM approaches with learners aged 3 to 15 years. A total of eight local authorities are participating in this Raising Aspirations in Science Education Pilot (RAiSE) pilot from August 2016 to June 2019. The authorities were chosen to represent a diverse range of contexts including large and small urban and rural authorities.

In addition to the funding from The Wood Foundation, funding is being made available from Scottish Government and also from the participating authorities themselves. This funding is being used by each local authority to recruit a dedicated development officer to coordinate professional learning in science and STEM for practitioners across their local area. A key aspect of their work involves harnessing all the support available locally for STEM, from employers, colleges, universities and science centres, to ensure schools have sustainable partnerships in place to help them continue on their STEM journeys. The programme is being externally evaluated and the interim findings[4] are very positive.

Although these two programmes were initiated before the inception of the STEM Strategy they proved to be extremely useful laboratories of innovation to trial new approaches and better understand the practical challenges involved in developing STEM approaches in a wide variety of contexts. In essence, they enabled a three-step model of improvement to be followed whereby one small test of change is developed, evaluated and used to inform the next iteration of development.

[4] *RAiSE Interim Report: Robert Owen Centre for Educational Change (April 2018): link to be inserted when report goes live.*

The STEM Challenge

The publication of the STEM Education and Training Strategy in October 2017 marked the end of a year-long process of consultation, reflection and partnership working across Government Directorates, agencies and with key stakeholders. The Strategy proposes a five-year plan of action involving early learning and childcare, primary and secondary school settings, colleges and universities, and also the community learning and development and adult education sectors.

The Strategy forms a part of national policy and is being led by The Minister for Further Education, Higher Education and Science. The implementation of the STEM Strategy is supported by a National STEM Strategy Implementation Group and Advisory Group, appointed by the Minister and Scottish Government officials. Agencies such as Education Scotland and Skills Development Scotland play a central role in providing advice and guidance to inform policy and in implementing many of the major components of the Strategy.

The aim of the Strategy is to ensure a system-wide, concerted and coherent programme of action that is required to bring about the step-change we need. It also identifies a number of critical challenges that need to be addressed around four key themes: Connection, Excellence, Equity and Inspiration.

STEM Strategy theme: Connection

"When we try to pick out anything by itself, we find it hitched to everything else in the Universe."

John Muir, Scottish naturalist and conservationist and founder of the National Park Movement.

Scotland's STEM Education and Training Strategy was born into an exciting and fast-changing period in Scottish education and has to be understood within this context. The interconnected nature of STEM means it cuts across numerous policy areas relating to education and curriculum, skills development, science, technology and the economy. For those tasked with developing the Strategy, care was required to intricately weave it together with numerous other policies and strategies, both published and emerging including:

The Developing our Young Workforce (DYW) programme, established in 2014, aims to reduce by 40% the number of young people aged 16-24 who are unemployed. Twenty one DYW Regional Groups, led by industry, have now been established to promote partnership working between industry and schools. This includes improving the range and quality of work placements for learners, helping to develop the local curriculum offer, including development of skills to meet industry needs, and supporting an increasing range of pathways into the world of work for learners. Standards and guidance have been published[5] to support this work and ensure employability and career management skills are embedded within the curriculum for learners aged 3 to 18 years.

The National Improvement Framework, launched in 2016, sets out a single, definitive plan for securing educational improvement in outcomes for learners in Scotland with a focus on literacy, numeracy and health and wellbeing. The framework has led to the introduction of new standardised assessments and a strong national focus on closing the attainment gap between learners from the most affluent and deprived communities. The programme has been built around six drivers of improvement:

- *School leadership*
- *Teacher professionalism*
- *Parental engagement*
- *Assessment of children's progress*
- *School improvement*
- *Performance information*

The Scottish Attainment Challenge, launched in 2015, is underpinned by the National Improvement Framework and provides universal and targeted support in specific authorities to raise the attainment of learners from our most deprived communities. An attainment fund of £750 million GBP (860 million Euros) has been set aside for this fund over a five year period. STEM, therefore, has to demonstrate its purpose and value in terms of promoting engagement in learning and raising attainment, especially from our most deprived communities.

[5] Career Education Standard, Work Placement Standard and School Employer Partnership Guidance: https://education.gov.scot/what-we-do/Developing%20employability%20and%20skills

Education Governance: Next Steps – Empowering our Teachers, Parents and Communities to Deliver Excellence and Equity for Our Children (2017) ushers in significant changes to the way Scottish education is governed. Improvements in education will now be led by six new regional collaboratives, comprising groupings of local authorities and resources from Scotland's national education body, Education Scotland.

15 to 24 age group is as efficient and effective as possible and provides stepping stones to success for those needing most support. The Review, set up in 2016, has been considering the journey from the senior phase of school (15 to 18 year olds) leading to employment, including the stages of further and higher education in college, higher education in university, vocational training and apprenticeships. The aim of the review is to ensure that all learners are on the right route to the right job, through the right course via the right information.

Digital learning and teaching strategy (2016) seeks to create the conditions necessary to allow all of Scotland's educators, learners and parents to take full advantage of the opportunities offered by digital technology. It aims to give all of our learners the opportunity to improve their educational outcomes and to develop digital skills, including Computing Science, which are vital for life, learning and work in today's increasingly digitised world. The benefits of this strategy also extend to our teachers and early learning and childcare practitioners and parents and carers and also the digital industry and wider economy.

The Vision 2030+ Report (2016) recognises learning for sustainability as an entitlement for all learners within Scotland's curriculum. Incorporating education for sustainable development, global citizenship and outdoor learning, learning for sustainability is recognised as a theme across all learning, including STEM. Application of STEM learning to contexts such as citizen science, climate change, ecological systems and the circular economy will be a feature of work going forward. This will complement work in Scottish schools to learn about the United Nations Sustainable Development Goals and will be further supported by our world-leading Eco-Schools Programme, in which 98% of our state schools participate.

In further and higher education, colleges have also undergone a significant process of change. This has involved the incorporation or merger of forty three smaller colleges in August 2010 to 21 regional colleges. Among a number of high-level benefits, this process of regionalisation was initiated to improve planning, coordination and delivery of skills provision within regions to better meet the needs of employers and the economy[6]. In the university sector, there is strong political drive to widen access[7] and increase the enrolments of learners from our most deprived communities onto university courses.

The publication of the STEM Education and Training Strategy is seen as a key connecting piece of the education policy landscape in Scotland, or a golden thread, that can tie together many of the ambitions of other policies. STEM is recognised as a providing relevant, hands-on and motivational context for learning that can help to engage learners and raise attainment. STEM also offers a range of new pathways for learners, both in terms of traditional academic routes to university but also to skilled trades, apprenticeships and further vocational study.

[6] *Impact and success of the programme of college mergers in Scotland. (Scottish Funding Council, 2017). http://www.sfc.ac.uk/web/FILES/ReportsandPublications/College_mergers_overarching_report.pdf*

[7] *Working to Widen Access. (Universities Scotland, 2017). https://www.universities-scotland.ac.uk/wp-content/uploads/2017/11/Working-to-Widen-Access.pdf*

STEM Strategy theme: Connection

Practitioners are central to the success of any education system. Scotland, like other European nations, is facing an increasing challenge in recruiting sufficient numbers of STEM practitioners to fill vacant posts. This problem is likely to be exacerbated as the demand for highly-qualified STEM graduates grows and as salaries within industry increase accordingly. The Scottish Government, in partnership with university initial teacher education institutes and the General Teaching Council of Scotland, has introduced flexible new routes into teaching to attract more people into the profession. Recruitment campaigns like Teaching Makes People will continue to be supported. Bursaries of £20,000 are now also being offered to individuals who have opted to change their career and embark on teacher training programmes in priority subjects, including STEM subjects. This is to provide financial support during their training year.

Retention is equally important as recruitment and the provision of high-quality professional learning is critical in this regard. Across all the sectors being targeted, the professional learning component of the STEM Strategy will need to meet the needs of some 86,000 practitioners. This presents a significant challenge, especially as the shortage of STEM teachers means that many schools are unable to find cover for teachers to attend STEM training.
The ongoing financial constraints have also led to a reduction in quality and improvement support officers at local authority level. The STEM Strategy proposes that a team of Regional STEM Advisors should be appointed to lead and coordinate provision within each of the new Regional Improvement Collaboratives being established following the Governance Review. These lead officers will be employed by Education Scotland. They will have a key role to play in ensuring a consistent level of support and leadership for STEM across the authorities and for support networking, mentoring and collaboration between practitioners to allow for effective sharing of practice. The STEM Advisors will also strengthen partnership working between RAISE Development Officers where they exist and with colleges and DYW Regional Groups of employers.

Within the Strategy, Scotland's colleges are being invited to take on an enhanced role as STEM hubs to provide professional learning for practitioners. The colleges are well-placed to take on this role for STEM given the lead role they are playing in delivering STEM Foundation[8] and Modern Apprenticeship[9] Programmes and also because of the extensive links they have with STEM employers. The needs of the early learning sector and the community learning and development sector will also be met through an enhanced role for our four regional science centres and the twenty or so science festivals that operate around Scotland. The Strategy therefore will build and extend the capacity of STEM agencies, organisations and providers within the system to help them expand and extend their professional learning offer. The development of online learning and resources, led and coordinated by Education Scotland, will allow busy practitioners to access modularised learning in a place and time which suits them best. Although traditional training courses will still be part of the professional learning mix, there will be an increased emphasis on collaborative and co-development of professional learning and experiential visits to colleges and industries to learn more about STEM pathways, workplaces and the needs of industries.

[8] *Foundation Apprenticeship Programmes. (Skills Development Scotland). https://www.skillsdevelopmentscotland.co.uk/what-we-do/our-products/foundation-apprenticeships/*

[9] *Modern Apprenticeship Programmes. (Skills Development Scotland). https://www.skillsdevelopmentscotland.co.uk/what-we-do/our-products/modern-apprenticeships/*

Education Scotland has published a guide[10] to support the self-evaluation and improvement journeys of early learning centres and schools. Aligned to the Scottish inspection framework, How good is our school? [Fourth edition], the guide exemplifies features of highly effective practice in whole-setting approaches to STEM.

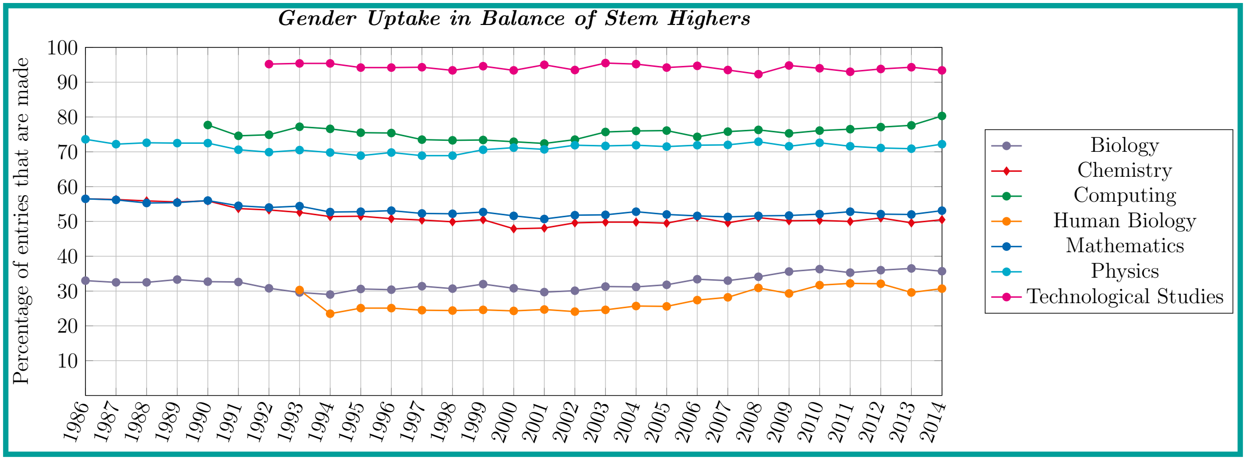
The Strategy also sets out the route to excellence in research and promoting links with industry. Universities and colleges will be supported to better coordinate and align their STEM offers to ensure they meet industry needs and help Scotland achieve its economic ambitions. The Innovation Centres, launched by the Scottish Funding Council in 2012 to promote transformational collaboration between universities and industry, will continue to use their unique perspective to inspire school pupils to STEM skills for emerging careers in areas such as bioengineering.

STEM Strategy theme: Equity and equality

The STEM Strategy, in alignment with the wider policy context in Scotland, has a strong focus on tackling inequity and in building a more equal and socially just society in Scotland. This includes a firm commitment to tackle the gender imbalance that has stubbornly persisted in STEM subject areas the last 30 years (See Figure 1). In 2016, over 70% of learners taking physics, 80% of those taking computing science and 93% of those taking technologies at Higher qualification level (taken at approximately 17 years of age) are boys. Conversely, only 36% of those taking Higher Biology are male. This imbalance persists beyond school with males representing 66% of STEM-related college enrolments in 2015/16 and 93% of STEM starts on Modern Apprenticeship programmes. At university level, women were more represented in subjects associated with care. They made up 81% of enrolments in subjects allied to medicine and 78% in veterinary science but just 18% in engineering & technology and 20% in computer science. Addressing the gender in STEM issue has a significant role to play in tackling the gender pay gap within the wider workforce given the predominance of males in the high-paid STEM industries and over-representation of women in low paid health and childcare sectors.

To improve gender balance in STEM in early learning and childcare settings and schools, a three-year pilot programme was established to develop effective evidence-based approaches (see case study 3). As with the National STEM Project, this Improving Gender Balance programme has proven to be invaluable in preparing the ground for the National STEM Education Strategy. The ambition now is to develop an effective implementation plan to extend the reach of the Improving Gender Balance programme to all schools and centres by 2022. A key challenge will also be to link the work in schools closely with the strategies for further and higher education and apprenticeship programmes (as set out in Skills Development Scotland's Modern Apprenticeship Equality Action Plan and also the Scottish Funding Council's Gender Equality Action Plan). Further work is being led by the Royal Society of Edinburgh to refresh their Tapping All Our Talents study to ensure coherent national approaches to gender in STEM. The aim is to tackle the 'leaky STEM pipeline' whereby women fall away from STEM courses and jobs at key transition points through education and early parts of their career. This situation results in a STEM workforce in Scotland which is only 20% female.

[10] *STEM self-evaluation and improvement framework. (Education Scotland, 2017). https://education.gov.scot/improvement/learning-resources/STEM-self-evaluation*



↑ ***Figure 1:*** *Update of STEM subjects. The data shown is an amalgamation of traditional and CfE Highers and in some instances English and Gaelic-medium Highers.*

Beyond gender, the national focus on STEM provides a significant opportunity to make science, technologies, engineering and mathematics courses and training more inclusive of all learners. Traditionally, the sciences and mathematics Higher qualifications, taken by learners in their fifth year of secondary school at approximately 17 years of age, are viewed widely as being amongst the most difficult and aimed primarily at high-performing learners who intend to pursue further study at university level. Nationally in Scotland, some 35,716 learners take Higher English each year compared to only 18,861 taking Higher Mathematics. In sciences, there is a significant under-representation and underperformance of learners from deprived households in science classes. For example, in Physics more than double the percentage of school leavers from the least deprived quintile achieved a pass at National Qualification level or better compared with those from the most deprived quintile. In 2016, nearly 40% of school leavers from the least deprived quintile held a Higher or better pass in Mathematics. This compared with less than 10% of those from the most deprived quintile.

For a significant proportion of learners, therefore, the traditional National Qualifications have presented a barrier to rewarding STEM careers, which often do not require graduate-level qualifications.

Scotland's Developing Young Workforce Programme, now half-way into its seven year lifespan, is starting to have an impact in this respect with an increasingly diverse range of qualification pathways on offer.

These often involve a combination of school, college and work-based learning. By 2019, some 5000 school-age learners, for example, will be starting Foundation Apprenticeships which have been designed in partnership with employers to meet labour market needs. The number of young people gaining skills for work qualifications and other awards has also increased to 50,148 in 2017. These alternative pathways have been specifically designed to meet the needs of a wider range of learners and to support their progression in positive post-school destinations. There is a strong focus and provision for STEM within this offering with 7 out of 11 Foundation Apprenticeship frameworks and 38 out of 105 Modern Apprenticeship frameworks being STEM-related.

A major focus of the DYW programme is on four identified groups of learners who face challenges and barriers in accessing positive destinations. The identified groups include:

- *gender*
- *black and minorty ethnic communities*
- *disabled young people*
- *learners who have experience of being looked after by the state*

The latter group have the worst outcomes of any group of learners in Scotland with only 4% progressing onto study at Higher Education level in 2014/15 compared to 39% of all school leavers[11].

Providing these alternative pathways and opportunities for STEM-related learning is only part of the solution. As these new pathways were introduced it has also proven challenging to persuade young people, parents and families to consider these options and to commit to them. Archer Ker, DeWitt, Osborne, Dillon, Wong, & Willis (2013), together with the Project STEM; Book of Insights report published by the Department for Business Innovation and Skills (2014), illustrate the often negative perceptions of STEM held by learners. This can lead learners to rule themselves out of STEM because they perceive themselves as not being sufficiently intelligent or because they perceive STEM to be only for high-performing academic students. Archer Ker, DeWitt, Osborne, Dillon, Wong, & Willis (2013) also revealed that young people often have a very narrow understanding of STEM careers: for example, perceiving that a science qualification could only lead to a career as a scientist or science teacher.

[11] *Education Outcomes for looked after children: http://www.gov.scot/Resource/0050/00501939.pdf*

Their research also introduced the concept of ‘science capital’ which is an important factor in persuading learners to continue with their science and STEM journeys. Science capital is the science-related knowledge, attitudes, experiences and resources that individuals acquire through life. It includes the science that individuals know, their attitudes and dispositions towards science, who they know (e.g. if their parents are interested or involved in science) and also the everyday engagement they have with science.

A key component of the STEM Strategy therefore is to build this science capital more widely, especially in deprived or under-served communities in urban, rural and remote settings. Within the DYW Programme this translates to a coordinated programme of targeted promotion of new STEM pathways to families, carers, guardians and communities within the four identified equality groups. More broadly within the STEM Strategy, Education Scotland, Scottish Government and the science centres and festivals are seeking to collaborate more effectively to extend the reach and engagement of deprived and under-served communities with science and STEM-related education and training programmes.

STEM Strategy theme: Inspiration

“…not all of those with STEM skills and qualifications take up STEM occupations or work in STEM industries when they leave the education system. Not enough people are sufficiently inspired on an ongoing basis to work in the STEM industries or to develop and maintain their STEM capability throughout their lives.”

STEM Education and Training Strategy for Scotland, 2017 (Page 26).

A core ambition of the STEM Education and Training Strategy is to provide all learners with access to high-quality and enriching STEM experiences that engage and motivate learners and their families and inspire more individuals to pursue further studies and careers in STEM. And where might this inspiration or vital spark come from? Through the exciting and meaningful STEM contexts and pedagogies that help learners understand the relevance of their learning to their current and future lives and careers.

Key to this is the successful engagement of Scotland's many STEM industries and sectors in our education and training programmes. An estimated 35% of Scotland's workforce is employed within STEM sectors including: energy, creative and digital media, life sciences, financial, food and drink and universities. Many of these sectors are experiencing significant recruitment challenges with an estimated 39% of employers seeking STEM skills already experiencing difficulties with recruitment.

Consequently, many employers are actively engaged in supporting STEM programmes, challenges, competitions and interventions in schools to ensure young people develop the necessary STEM skills and inspiration to encourage them to pursue careers in STEM sectors. Similarly, the UK-wide STEM Ambassador Programme has recruited 4000 STEM professionals in Scotland to engage with education and training settings. These STEM Ambassadors volunteer their time to support careers awareness events, visit classes and engage with teachers. In a similar way, universities and colleges also support an array of STEM programmes, interventions and partnerships with some undergraduates, post-graduates and academic staff also volunteering as STEM Ambassadors.

The involvement of this wide range of partners provides a rich landscape of STEM support which numerous schools have accessed effectively to help them on their STEM journeys and to improve outcomes for learners. However, the STEM Strategy recognises that further work is required to ensure a consistent and manageable offer is available to all schools and settings. In some cases, secondary schools in large urban settings can be overwhelmed by the variety of STEM activities and opportunities on offer – the so-called 'STEM blizzard'. Whilst, at the same time, early learning and childcare and primary schools and schools in rural or deprived areas may struggle to access the support they need.

The STEM Strategy aims to bring greater coordination to this through a network of new regional STEM Advisors, a new online directory of STEM interventions and activities and through the network of RAiSE STEM Development Officers working at local authority level. Another exciting action is for a new network of STEM Youth Ambassadors to be established to provide local leadership and inspiration in STEM to their peers. Further action has also been identified to extend the reach of the STEM Ambassador programme to ensure early learning and childcare, families and communities and rural and remote areas are equally well-served.

A permanent Learning for Sustainability Development Officer is also being recruited by Education Scotland and will be located in the team of STEM Advisors. One of their key functions will be to ensure that themes relating to ecology, sustainability, outdoor learning, global citizenship, children's rights and social justice are firmly embedded in the national, regional and local STEM activities and learning.

Furthermore, schools and employers are also being supported to develop strong and sustainable partnerships through the network of DYW Regional Groups. A national target is for every school to have a STEM partner by 2020. These multi-faceted partnerships are expected to enhance and transform the curriculum offer by helping to contextualise learning and enabling young people to develop key STEM skills to meet the needs of local industries.

Conclusion and reflections

Scotland is at a watershed moment in terms of its approach to STEM. As with other nations within Europe and beyond, we face fundamental challenges in the way we prepare our learners and citizens for life in an increasingly scientific and technological age. Our industries require increasing numbers of individuals to develop STEM skills and aspire to careers in STEM-related industries and sectors. The future success of our economy, therefore, depends on the success of the newly published STEM Education and Training Strategy. The process of developing such a national strategy, although challenging, provided an incredibly valuable opportunity for us to reflect on the richness of what we have already and to consider holistically, how we might drive forward further improvement to enable us to build a successful STEM Nation.

Based on our experiences we offer the following reflections:

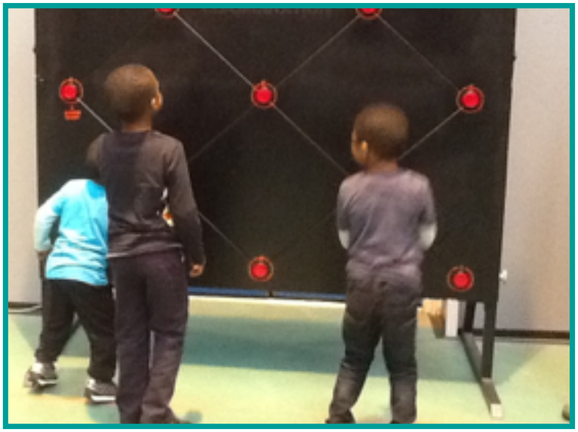
1. *STEM contexts, which weave sciences, technologies and mathematics together through interdisciplinary learning, provide rich learning opportunities which can engage and motivate learners. They have a key role to play in improving pedagogy through enquiry-based approaches and equipping young people with skills for learning, life and work.*
2. *STEM can act as a golden thread weaving many policy areas together, from education to skills and workforce development to economic regeneration. It can therefore promote collaboration within and across education, government and industry sectors and help overcome silo-working.*
3. *Strong political support is required to bring about system change across many government departments and policy areas. It is crucial that all stakeholders are included in the development process and have ownership of STEM strategies that are developed to ensure effective system-wide alignment and engagement.*
4. *There is tremendous value in taking a phased approach to developing a significant national strategy in a broad area such a STEM. Significant pilots over a two-three year timescale provide a valuable test-bed for developing innovative new approaches and partnerships which can be scaled up within the context of a national strategy.*

Case study 1 – Sci-Fun Family Day

This case study details a SCI-FUN Family Day hosted at the West Pilton Community Centre, Edinburgh, in July 2017.

Research suggests that visitors to science centres – which can contribute towards science capital – tend to be 'overwhelmingly white and middle class'. The North West locality in Edinburgh has the highest percentage of black and minority ethnic young people under the age of 15 years and West Pilton is one of the most deprived communities in the Edinburgh area.

The University of Edinburgh approached the City of Edinburgh Council with a proposal to collaborate on a pilot project to offer a 'science centre experience' through its SCI-FUN scheme, providing access to science and technology activities to an under-served community. During the event, some 200 local young people and their families attended and had the chance to engage with interactive science exhibits staffed by university undergraduate students.



The local police force attended the event and engaged with the visitors which enhanced the community focus. Additionally, the centre operated a table sale and café which was well attended and increased footfall on the day.

The key finding from the event was that visiting informal science learning environments and talking to others about science engages parents and young people and helps to build science capital. Evaluations demonstrated that 82% of those randomly polled rated the experience very positively, awarding it either 9 or 10 out of 10.

It would be useful in future to compare whether informal community-based events such as the SCI-Fun West Pilton event more effectively engage people in deprived communities than well-established science centres and festival attractions.

Case study **2** – Port Ellen Primary

Port Ellen Primary on Islay is an award-winning school that has a passion for STEM.

The resourceful staff engaged learners of all ages in many exciting and motivating STEM learning experiences such as:

- *Practical investigations on plate tectonics and construction of pneumatic monsters*
- *Participating in the rocket seeds experiment using seeds that have been to the International Space Station*
- *Taking part in the Scottish Mathematics Challenge*
- *Learning about algorithms, computational thinking and game design*
- *Linking STEM to learning for sustainability through Eco-Schools topics.*

The school also makes use of its stunning location on a remote Scottish island to bring STEM to life by working regularly with the Royal Society for the Protection of Birds and by visiting the Hebridean Whale and Dolphin Trust boat to enhance learning about animal communication. They are also working with Reading University archaeologists to carry out geophysical surveys of historic sites on Islay.

The school is working with colleagues from other schools to promote effective cluster-wide approaches to science and student STEM ambassadors from Islay High help run a popular after-school club.

Maureen McDonald, Headteacher of Port Ellen Primary explains:

"As educators at Port Ellen Primary School, it is important that we equip our children with skills for learning, life and work. Through our work in STEM, we have created a culture and environment that enables our learners to apply their thinking in real-world applications. Our interdisciplinary methodology in STEM is a creative and inclusive approach which stimulates and motivates the youngest to the oldest learners. When children are interested and engaged to this level, it not only helps to raise attainment and achievement, it also harnesses the enthusiasm of our parents, partners and community creating a STEM domino effect".

Case study 3 – Promoting Gender Balance in STEM

In 2015, Education Scotland embarked on a three year pilot programme to develop evidence-based approaches to tackling gender imbalance in STEM subjects. This was taken forward in partnership with our national skills agency, Skills Development Scotland, and the Institute of Physics. The programme was part of a wider body of action research which also involved schools in England.

The two dedicated gender balance officers employed to lead the pilot in Scotland supported five identified secondary school clusters to develop a range of interventions including whole school equality programmes, class observations, audits of course materials and books, professional learning workshops on unconscious bias etc. Professional learning was also provided to careers information and guidance staff. The keen interest from STEM providers and organisations in this work meant that wider engagement and support for a wide range of stakeholder organisations became a significant feature of the pilot too and an important way to extend the impact of the learning beyond the school clusters immediately involved.

The pilot phase of the Improving Gender Balance in STEM Programme concluded in March 2018 and was positively evaluated through an evaluation led by Skills Development Scotland. A rich bank of resources[12] has now been published and a national training programme developed. The pilot provided a rich opportunity for learning for all partners involved. These key points have been captured in the final pilot report and include the:

- *Complexity of the gender issue and the importance of a sustained whole school or setting approach to address it*
- *Importance of engaging with all sectors especially early learning and childcare where stereotypes can already be deeply ingrained*
- *Skill needed to challenge myths around stereotyping and help people recognise the issues within their settings and communities*
- *Challenge of engaging parents and families to tackle cultural practices and norms*
- *The need to also address the underperformance of boys in schools and lack of male representation, especially from deprived communities, at university level and in subjects like life sciences and biology.*

A new team of Improving Gender Balance and Equality Officers is being recruited by Education Scotland to extend the learning from this pilot to all schools in Scotland by 2022.

[12] Improving Gender Balance resources: https://education.gov.scot/improvement/learning-resources/Improving%20gender%20balance%203-18

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Authors

Els Belien

Els Belien holds a master of Science (bio-chemistry) in Industrial engineering. From 1997 until 2012 she taught chemistry, physics and biology at a secondary school. Afterwards she worked as an examiner for sciences on the examination board of the Flemish community. Since 2016 she is part of the Qualifications and Curriculum Division of AHOVOKS[1], where she is responsible for natural sciences and STEM in the Flemish curriculum.

Hannelore Baeyens

Hannelore Baeyens studied educational sciences and followed a teacher training at the university of Ghent. She works for the Qualifications and Curriculum Division of AHOVOKS. There she coordinates the process of the development of educational goals for compulsory education as well as the development of educational qualifications.

[1] Agency for Higher Education, Adult Education, Qualifications and Study Grants

Abstract

To deal with the shortage of (qualified) human capital in STEM professions and to reduce the high levels of youth unemployment, the Flemish Government launched the STEM action plan (2012-2020). This action plan created a new dynamic in the Flemish educational and professional landscape resulting in a multiplicity of initiatives and a strong cooperation between stakeholders. As the various employment sectors and (educational) institutions were attributed responsibility for developing a number of actions from the plan, STEM learning Networks took shape.

The article describes on the one hand the presence and quality of STEM competencies, namely problem-solving, research and design skills, in the Flemish education in recent years, and on the other hand the initiatives launched for enhanced STEM integration and quality as well as the impact of it all. The STEM framework, new didactic models for STEM and the translation of the STEM vision into the renewed Flemish educational curriculum are described in more detail. The vision 'integration of mathematics, science and technology into a problem-centered learning environment without compromising on the individuality of the separate disciplines' is translated into transversal and substantive educational goals. Both kinds of educational goals must be combined by the schools to realize integrated STEM education in Flanders.

A STEM-aligned educational policy in Flanders

Introduction

As is the case in most European countries, the Flemish community has been keen to focus on STEM (Science, Technology, Engineering and Maths) for several years. In 2004, the Government of Flanders launched initiatives and actions to encourage STEM learning and to apply it in formal (compulsory education) and non-formal contexts. The TOS21 project (2004-2008) was the starting point of Flemish STEM education and aimed to develop a learning path from nursery to secondary education to encourage a broad education in science and technology. This project contributed to the introduction of technical literacy into Flemish education.

In 2012, the Government of Flanders went a step further, in response to the results of the Lisbon Objectives (2000-2010) , which revealed that Flanders scored slightly lower than the European average (20.9% versus 37.2%) on the increase in the number of graduates in mathematics, science and technology. The STEM action plan (2012-2020) was launched, placing the focus on STEM subjects. In recent years, this resulted in actions and initiatives at the macro, meso and micro level[2], with the objectives of: *"increased human capital in STEM domains in order to better meet the needs of the knowledge-based economy and labour market, an increase in the number of qualified people entering and graduating STEM bottleneck courses in relation to the reference year 2011 (both higher education and secondary education), and to eliminate the extreme gender imbalance in certain STEM study areas and courses"*[3].

In order to promote involvement and participation in this STEM action plan, the various Flemish employment sectors and (educational) institutions were attributed responsibility for developing a number of action points from the plan. This participation led to mutual partnerships between educational institutions and between educational institutions and employment sectors - the so-called STEM Learning Networks - in addition to questions concerning the quality of the science, mathematics and technology education.

This article describes the evolution of STEM education in Flanders and clarifies the current STEM vision. The first section zooms in on the current quality of STEM education: the way in which STEM skills, namely problem-solving skills, research and design skills, are incorporated into the current curriculum. The second section provides insight into initiatives launched for enhanced STEM integration and quality: the development of a STEM framework on the one hand, and specific STEM didactic models which result from scientific research facilitated by the government on the other. The third component describes the translation of the current STEM vision into the development of a new Flemish STEM curriculum. Lastly, we zoom in on the first outcomes in STEM education as a result of the initiatives and actions taken.

[2] *Macro level = policy level; meso level= school institutions, educational umbrella organisations; micro level = class level*

[3] *STEM action plan: Https://onderwijs.vlaanderen.be/nl/wat-is-het-stem-actieplan*

The quality of STEM education in Flanders

The precise interpretation of STEM in Flanders is based on the following definition: ‘STEM is about building scientific, technological and mathematical insights, concepts and practices (S, T & M) and using these to solve complex questions or actual problems (E). Within education, STEM is thus - above all - the pooling of the various acronym components in order to identify scientific challenges in relation to each other and to resolve and communicate these’[4].

In Flanders, the realisation of this vision including the STEM action plan goals, follows a specific and characteristic structure in which a strict delimitation of powers prevails. The government determines “what” must be taught, resulting in the setting of minimum goals that encompass knowledge, insight, skills and attitudes. These targets are captured in a curriculum and the educational networks, umbrella organisations[5] and schools are free to determine the method (pedagogical-didactic approach) with which these will be realised within their pedagogic project. The Education Inspectorate monitors the realisation of the educational goals at meso and micro level. The government can also assume a facilitating role in relation to pedagogical-didactic actions that arise from the educational field. This specific delimitation makes shaping STEM education in Flanders a huge and challenging task for the policy makers and various educational players.

[4] STEM framework: https://www.vlaanderen.be/en/publications/detail/stem-framework-for-flemish-schools-principles-and-objectives-1

[5] There are 3 educational networks. Within each of these are one or more educational umbrella organisations. The umbrella organisations support and represent the school boards. They devise curriculums and class timetables, which the school boards can adopt.

Problem-solving, research and design skills in the current educational curriculum

The Flemish government establishes the educational goals that are deemed necessary and attainable for specific student groups in Flanders. These educational goals belong to a specific subject or are cross-curricular. To verify whether typical STEM skills have a place in today's educational curriculum, both subject-related and cross-curricular goals must be screened. This reveals that problem-solving, research and design skills are, indeed, being asked of the pupils, but not in an integrated (STEM) way.

Examples of educational goals:

- *Problem-solving skills in mathematics (first grade):*

  Pupils can solve simple questions that can be traced back to a first-grade comparison with one unknown.

- *Research in natural sciences (second grade):*

  Under guidance, pupils can apply the following aspect of scientific methodology when researching a scientific problem: performing an experiment, measurement or field observation using a proffered methodology and thereby correctly handling specific material.

↑ ***Figure 1:*** *Examples of educational goals*

STEM skills are addressed in the teaching matter per component, namely mathematics, natural sciences and technology, but cross-component and cross-context to a lesser extent. The table below provides an overview of the subjects and educational attainment levels in which specific STEM skills are addressed.

↓ ***Figure 2:*** *STEM skills in the various educational attainment levels and subjects*

Educational attainment level					
Specific STEM skills	Nursery education	Primary education	First grade secondary education	Second grade secondary education	Third grade secondary education
Problem-solving skills			Natural Sciences: scientific skills		Natural Sciences: science and society
	Mathematical concepts	Mathematics		Mathematics (aso, tso, kso)[6]	
				General Subjects Project (bso)[7]	
	Technology		Technology		
			Learning to learn		
			Learning to learn		
Research and design	Nature and technology		Natural Sciences: scientific skills		
			Technology	Sciences[8]	Sciences[9]; integrated test (tso, kso, bso)
			Cross-curricular educationa goals		

[6] aso: general secondary education (theoretical study courses); tso: technical secondary education (practical technical study courses); kso: art secondary education (practical technical study courses)

[7] bso: secondary vocational education (practical study courses)

[8] In the specific educational goals for aso

[9] In the specific educational goals for aso

An exception to this is the compulsory integrated test (GIP) in the practical (bso) and theoretical and practical (tso/kso) study courses in the third grade of secondary education. This is a practical test that offers pupils the opportunity of achieving the required knowledge, skills, insights and attitudes in an integrated, cross-curricular and practical way, in a real context. Various subjects are covered in the project that the pupil delivers.

Thus, giving the integration of STEM skills and STEM teaching matter in authentic problem-solving contexts a clear place in the educational curriculum for all pupils, presents a major challenge to the Government of Flanders when it comes to the planned actualisation of the educational goals for nursery, primary and secondary education in the years ahead.

STEM quality in Flanders

One of the action points arising from the STEM action plan was to investigate the quality of STEM education. During the 2012-2013 school year, the Education Inspectorate evaluated STEM subjects[10] in nursery, primary and secondary education, with the aid of a quality viewer, which is based on (international) research and complies with the Flemish Education Council's[11] STEM review. Both the presence of specific STEM skills and the degree of integration of the four STEM components into meaningful contexts formed part of the investigation. The table below provides a concise summary of the investigation results .

[10] Nursery education: mathematical concepts, world orientation - Primary education: mathematics, world orientation and ICT - Secondary education: mathematics, natural sciences, geography and technology

[11] Flemish Education Council (VLOR): the strategic advisory council for the Education and Training policy area

[12] Problem-solving, research and design skills

Educational attainment / Element from the Quality Viewer	Nursery education	Primary education	Secondary education - in STEM study courses
The educational offering is relevant, substantively correct and goal-oriented	Insufficient quality of the subjects investigated	The desired quality was only achieved for mathematics	Insufficient quality of the subjects investigated
Knowledge, insights, skills and attitudes are applied and integrated in a meaningful context in the STEM learning areas, domains and subjects	The quality is in line with the desired quality	Transfer-promoting frameworks are lacking	In the third grade, attention is given to integration with other courses
Educational practice encourages processes such as investigative, problem-solving and creative thinking	Desired quality is achieved	Increasing focus on problem-solving and creative thinking	Increasing focus on problem-solving and creative thinking
The application of design skills - within the technical process - receives explicit attention		Limited data available, which says nothing about the quality but rather a lack of design skills (either in the curriculum or in the schools' offering)	Acquired in the first grade; sufficiently present in the second and third grades of tso, lacking in aso

↑ ***Figure 3:*** *Results summary of the four quality viewer elements related to STEM skills and STEM content*

As with the educational goals analysis, the results of this investigation suggest that there is also a large margin of growth in classroom practice concerning the integration of the (four) STEM components and STEM skills into STEM contexts.

Based on these findings, the Education Inspectorate formulated a number of recommendations: adapt the imposed curriculum according to the STEM action plan, develop a strategy to ensure that STEM content is better aligned to STEM curriculum goals[14] and encourage professional development and formulate in-service training themes that focus on the development and application of a high-quality STEM didactic for all educational attainment levels.

[13] Report Education Inspectorate: https://www.vlaanderen.be/nl/publicaties/detail/onderwijsspiegel-2014-jaarlijks-rapport-van-de-onderwijsinspectie-1

[14] Curriculum goals: goals at the micro level, derived from he educational goals (macro level)

The quality of STEM education in Flanders

The STEM framework

In response to the Education Inspectorate's recommendations, the Government of Flanders decided to compose a STEM framework (2015)[15]. The STEM framework is a quality framework for STEM, developed by the Department of Education and Training and serves as a set of guidelines for STEM teachers. It comprises 10 dimensions and principles, which STEM teachers can adopt in order to teach in a STEM-aligned fashion. The problem-solving, research and design skills (dimension 2 and 3 of the STEM framework, also listed below) and the interaction between the four STEM disciplines, as well as the integration into STEM contexts (dimension 1 and 4 of the STEM framework, also listed below) are explicitly addressed:

1. *Interaction and correlation of the separate STEM acronym components with respect for the individuality of each component*
2. *Problem-solving learning via the application of STEM concepts and practices*
3. *Skilled and creative research and design*
4. *Thinking and reasoning, modelling and abstracting*

Teachers and schools are already using the STEM framework as a supplement to the existing curriculum. However, it appears difficult for them to implement this STEM framework in conjunction with the educational goals. Spontaneous mutual partnerships therefore arose between educational establishments and between educational establishments, companies and academics, which resulted in STEM Learning Networks for nursery and primary and secondary education. These STEM Learning Networks promote the sharing of expertise, and the learning from and with each other.

New didactic models

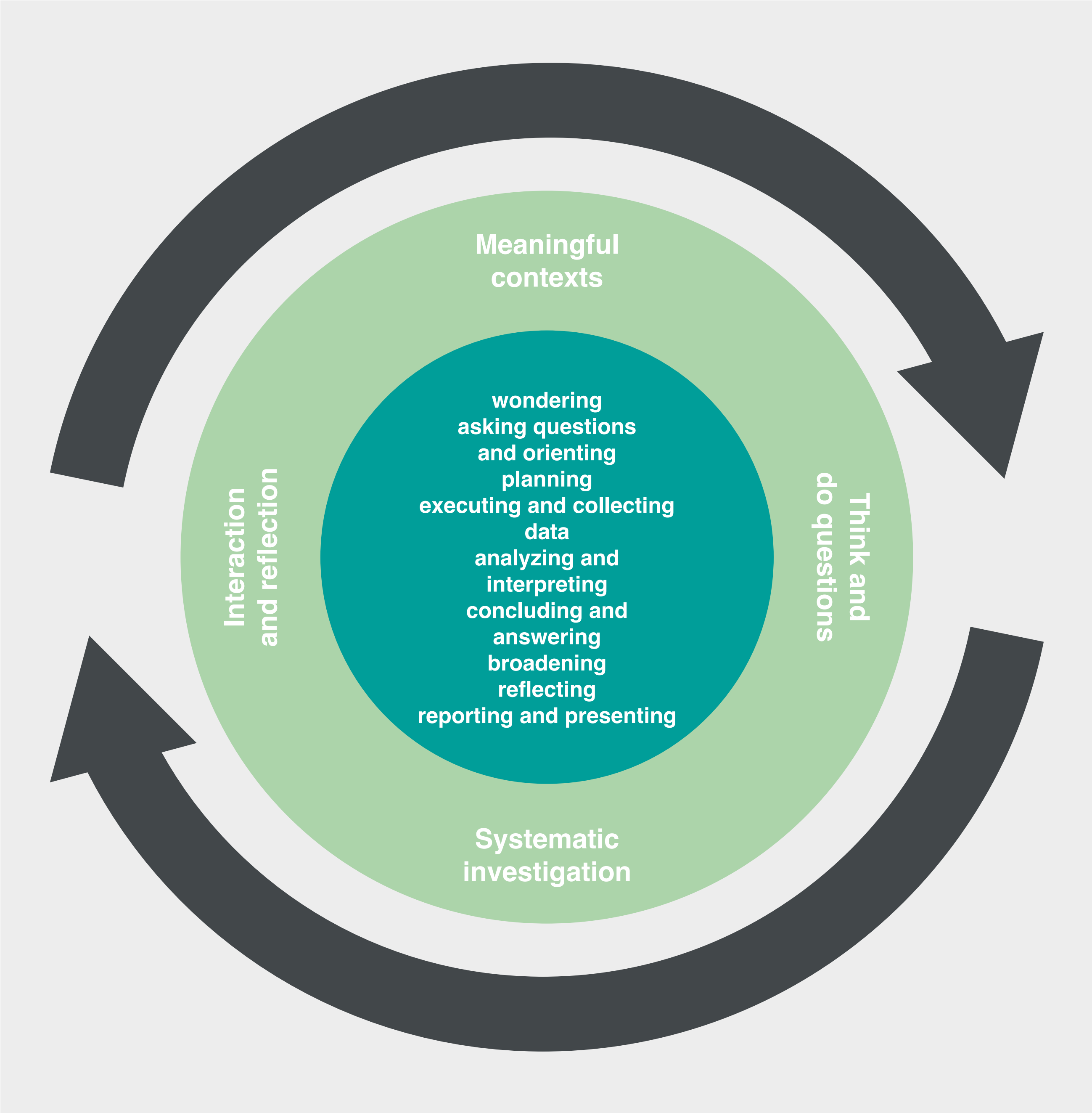
The Government of Flanders facilitates the STEM Learning Networks for nursery, primary and secondary education, as well as academic research projects. The Learning Networks operate independently from one another and, wherever possible, endeavour to provide solutions to the questions and concerns that arise in practice. As it is apparent from various studies, including that of the Education Inspectorate, it is not always clear to teachers how the various STEM components can be offered in an integrated way.

The STEM Learning Network for nursery and primary education therefore placed the focus on a specific STEM didactic for nursery and primary education and used a research project to develop the 'PK model'[16], a supportive didactic model for teachers[17]. In this model, inquiry-based learning is central to ensuring that the skills and insights, necessary for solving problems, are harnessed in an inter-disciplinary manner. The model comprises 4 pillars, P in the PK model, surrounded by 10 key components, K in the PK model.

[15] *STEM framework: https://www.vlaanderen.be/en/publications/detail/stem-framework-for-flemish-schools-principles-and-objectives-1*

[16] *PK model: Http://www.onderzoeksreflector.be/didactiek/stem-onderwijs-en-onderzoekend-leren/het-pk-model*

[17] *De Jonckheere, P.; Vervaet, S. & Van de Keere, K. (2016). STEM-didactiek in het Kleuter- en het Lager Onderwijs: het PK-model. http://www.onderzoeksreflector.be/sites/default/files/STEM%20Didactiek%20%282%29.pdf*



↑ ***Figure 4:*** *Schematic presentation of the PK model*

The 4 pillars, (1) meaningful contexts, (2) think and answer questions, (3) systematic investigation, (4) interaction and reflection provide teachers with guidance on applying STEM education in the classroom. They form the foundations for establishing STEM activities. The key components are 10 observable behavioural indicators that may manifest in the pupils, either spontaneously or from suggestions made by the teacher. The pupil's behaviour stems from the approach that the teacher has established from the 4 pillars and thus provides an important basis for interim evaluation and feedback. A nursery and primary education teacher who optimally exploits these pillars and core components teaches in a STEM-aligned fashion, encourages problem-solving thinking, establishes connections with the world and works in an interdisciplinary way.

This method is currently being used and tested in nursery and primary education. Whether this method is effective for STEM education remains to be seen.

The STEM@school[18] research project (2014-2018) was initiated in order to support and reinforce the STEM subject-related didactic in secondary education. The aim of the project is to provide secondary schools with the opportunity of offering well-integrated STEM education. Institutions of Higher Education and educational umbrella organisations were involved in order to ensure both sufficient scientific substantiation and sufficient support. The focus of this project is primarily on the design, implementation and validation of an iSTEM (integrated)-didactic that is based on 5 pillars: (1) integration of STEM content with respect for the individuality of the separate STEM components, (2) problem-centred learning based on genuine problems, (3) research- and design-based learning, (4) collaborative learning and (5) incorporating subject-related didactic research results into further development. The project group developed usable teaching modules for 3rd, 4th and 5th grade general secondary education[19] which are tested in a pilot phase. These sample modules aim to familiarise STEM teachers with a research, problem-solving and design didactic, in order that they can later develop teaching modules themselves. The use of a programming language (PYTHON) is an important innovation in these teaching modules. The research group makes a strong plea for assimilating basic programming knowledge and computational thinking, basic digital information knowledge, the operation of computers and computer networks, the conscious use of current software, etc. into the updated curriculum, as in the current social context, such competencies are essential for developing into a genuine knowledge-based economy. The advice from the STEM platform[20] was that young people must not only harness existing technologies but also learn to understand their underlying operation.

[18] STEM@school: http://www.stematschool.be/en/

[19] aso: general secondary education

[20] STEM platform: a group of independent experts that advises the Government of Flanders on the STEM action plan and proposes priorities - 5th advisory note (2016): https://onderwijs.vlaanderen.be/nl/stem-platform-en-stuurgroep

The key findings of the STEM@school research project[21] are listed below:

1. *Teachers who participate in curricular material development, show more profound reflections on activating instructional strategies in iSTEM*
2. *Training for the development of iSTEM learning modules should play the whole game, but in a junior version*
3. *Implementation of iSTEM depends on teachers' attitudes and school context factors*
4. *Teachers prefer traditional and/or their own assessment methods to evaluate students' learning outcomes during iSTEM*
5. *Students are more engaged during the iSTEM class than during regular STEM classes*
6. *iSTEM education increases students' interest in STEM*
7. *iSTEM education can have a positive impact on students' knowledge*
8. *Students struggle to apply the same concept in different contexts*

The STEM@school research project contributes to the scientific research literature and addresses the needs of practitioners and policy makers. Based on the results, the researchers give the following additional recommendations to guarantee a successful implementation of an iSTEM approach:

1. *Create a multidisciplinary iSTEM team*
2. *Principal/management support is crucial for success*
3. *Provide adequate opportunities for professional development*
4. *Provide pre-service training for teachers who want to learn about iSTEM*
5. *Continue to foster research on iSTEM practices and teacher design teams*

[21] *STEM@school. Developing and introducing integrated Science, Technology, Engineering and Mathematics education to Flemish secondary schools (project 130027). Final report. An IWT/FWO SBO project by Katholiek Onderwijs Vlaanderen, GO!, UAntwerpen en KULeuven (2018)*

New STEM vision in an updated curriculum

The entire curriculum[22], from nursery and primary education to the third grade of secondary education - including the STEM curriculum - is being updated within the context of the modernisation of secondary education[23]. The development of (re)new(ed) educational goals for the first grade of secondary education was initiated in the first half of 2018, with a view to implementation in September 2019. This phase is crucial because it will set out the future guidelines for STEM education in Flanders. To this end, the Government of Flanders is collaborating with academics, content experts, teachers and representatives from the education providers.

The renewed curriculum in Flanders is no longer based on subjects, but on 16 key competencies[24], which, in turn, are based on the European key competencies and the results of the social debate on educational goals[25] that was conducted with all the stakeholders in 2016. This includes competencies in mathematics, exact sciences and technology, learning competencies, digital competencies and media literacy. Building blocks are formulated for each of the 16 key competencies, which clarify the vision on education for all pupils in secondary education. They specify the major substantive foundations that must be worked through in secondary education. The concrete implementation of the building blocks is achieved via the educational goals, which vary according to the finality[26] of the study course.

The simultaneous development of first-grade educational goals for all the key competencies offers opportunities for establishing a highly coherent Flemish educational curriculum. By starting from the interrelationship between key competencies, educational content is not literally repeated in various places. Certain key competencies, including learning competencies, digital competencies, the development of initiative, ambition, entrepreneurship and career competencies, and also key competencies linked to citizenship, biopsychosocial well-being and cultural awareness and cultural expression, are transversal. The educational goals formulated below have a link to other substantive key competencies and are predominantly realised within the content of other key competencies.

[22] Curriculum: set of educational goals (knowledge, skills and attitudes) to be achieved at population level

[23] Moderisation of Secondary Education: https://onderwijs.vlaanderen.be/nl/modernisering-secundair

[24] 16 key competencies: (1) competencies in the field of physical, mental and emotional awareness and in terms of physical, mental and emotional health; (2) competencies in Dutch; (3) competencies in other languages; (4) digital competence and media literacy; (5) social- relational competencies; (6) competencies in mathematics, exact sciences and technology; (7) citizenship competencies including competencies for living together; (8) competencies concerning historical awareness; (9) competencies concerning spatial awareness; (10) competencies regarding sustainability; (11) economic and financial competencies; (12) legal competencies; (12) learning competencies including research competencies, innovational thinking, creativity, problem solving and critical thinking, system thinking, information processing and collaboration; (14) self-awareness and self-expression, self-management and agility; (15) development of initiative, ambition, entrepreneurship and career competencies; (16) cultural awareness and cultural expression.

[25] Report social debate on educational goals: Https://onderwijs.vlaanderen.be/sites/default/files/atoms/files/Van-Lerensbelang-eindrapport.pdf

[26] The finality of a study course indicates which priority a study course is preparing for: the labour market, higher education or both.

A vision for the future of mathematical, scientific and technological education in Flanders will be formulated. It will be inspired by the (European) key competencies, social debate on educational goals, international developments pertaining to STEM, ongoing national research, comparisons with international curricula (SLO-Nederland, NGSS, 21st century skills etc.), input from the learning networks, etc. Due to the individuality and specificity of the STEM disciplines and their integrated nature, the following vision is predetermined: *the integration of mathematics, science and technology into a problem-centred learning environment without compromising on the individuality of the separate disciplines.* This vision assumes that the knowledge and insights acquired from the various STEM disciplines are used to solve problems and queries in an integrated way.

STEM content will be given a place in the new Flemish educational curriculum in 3 ways. Firstly, as is already the case today, sufficient attention to the individual components will remain. Discipline-specific educational goals for mathematical, scientific and technological competencies ensure the necessary knowledge and insights.

↓

These educational goals are formulated according to 11 discipline-specific building blocks:

Building blocks	
Mathematical competencies	Developing insight into and dealing with numbers and quantities: theory of numbers.
	Developing insight into and dealing with space and form: geometry and applied arithmetic.
	Developing insight into and dealing with relationship and change: such as algebra, analysis and discrete structures.
	Developing insight into and dealing with data and uncertainty, such as calculation of probability and statistics.
	Building reasoning and abstracting, taking the coherence and structure of mathematics into account.
	Modeling and problem solving by analyzing, (de)mathematizing or using heuristics.
Scientific competencies	Developing insight into the construction, structure and properties of matter in living and non-living systems.
	Developing insight into the manifestations of energy, the interaction of matter with other matter and with energy, as well as the consequences of this.
	Developing insight into the basic properties of living systems.
Technological competencies	Developing insight into technological systems and processes and their relation to various technological domains and to other domains (science, mathematics, etc.).
	Designing, implementing, commissioning and evaluating technological systems, taking fundamental social, scientific and technological aspects into account.

↑ ***Figure 5:*** *Discipline-specific building blocks for the competencies pertaining to mathematics, exact sciences and technology*

Secondly, increased attention should be paid to the integration of the individual disciplines. To explain the physical world, to solve problems in daily life and to tackle social problems and challenges, specific knowledge and skills of mathematics, science and technology are necessary. However, typical STEM skills, such as researching, designing a solution, interpreting data and reasoning about choices are also crucial. These skills are based on many sub-skills: observing, measuring, experimenting, modeling, predicting, reasoning, calculating, analyzing data, ... Because of the strong mutual relationship between the disciplines - since you cannot do science without mathematics, no technology without science and no advanced mathematics without technology - having students solve integrated problems contributes to anchor the specific knowledge and skills and to experience the relevance of mathematics, science and technology. 'STEM educational goals' are developed for this reason. These educational goals are formulated according to the building block 'Applying scientific, technological and mathematical concepts and methods to solve problems and to investigate and understand objects, systems and their interactions'.

Thirdly, certain STEM content, such as problem and query solving, is not exclusively relevant to the STEM disciplines. Problem solving encompasses skills, such as asking the right questions, formulating a hypothesis, abstracting, modelling, formulating algorithms, creativity (generating ideas), being critical, interpreting data and interdisciplinary collaboration, which have been translated into transversal educational goals[27] for learning competencies, digital competencies, the development of initiative, ambition, entrepreneurship and career competencies, and for those key competencies linked to citizenship. One characteristic of these educational goals is that they must be realised in conjunction with the educational goals defined under other key competencies. This does not only involve content from the mathematical, scientific and technological key competencies. By embedding these in the curriculum as essential transversal educational goals and not exclusively attributing them to one substantive key competence, the Flemish government encourages their application in various domains and thus their transfer throughout the entire curriculum.

[27] *Transversal educational goals = goals that can be achieved in any discipline*

The educational goals linked to the following transversal building blocks are relevant for combining with STEM educational goals:

Building blocks	
Learning competencies including research competencies, innovational thinking, creativity, problem solving and critical thinking, system thinking, information processing and collaboration	Understanding and positioning yourself as a learner regarding learning in general and specific learning domains.
	Applying appropriate (learning) activities, strategies and tools to acquire, manage and process information digitally and non-digitally, taking the intended learning outcome and process into account.
	Recognising (and exploring) a (research) problem and finding an answer or solution using suitable (learning) activities, strategies and tools.
	Modeling and problem solving by analyzing, (de)mathematizing or using heuristics.
	Regulating learning views, process and results.
	Designing the learning process together.
	Applying domain-specific terminology, symbols and representations.
Digital competence and media literacy	Using digital media and applications to create, to participate and to interact.
	Thinking and acting in a computational manner.
	Dealing responsible, critical and ethical with digital and non-digital media and information.
Development of initiative, ambition, entrepreneurship and career competencies	Perceiving and exploring opportunities with the help of a creative thinking process.
	Exploring the feasibility of ideas, weighing up the use of resources versus goals and realising the chosen idea.
	Making (sustainable) choices, taking short- and long-term consequences into account.
Citizenship competencies including competencies for living together	Critically approaching the mutual influence between social domains and developments, and their impact on (global) society and the individual.
Competencies in the field of physical, mental and emotional awareness and in terms of physical, mental and emotional health	Achieving a safe lifestyle through the correct estimation of risk factors.

↑ ***Figure 6:*** *Relevant building blocks in terms of STEM integration*

When translating the educational goals into classroom practice, it is important to combine STEM educational goals with educational goals from the transversal key competencies. The transversal nature of problem-solving skills, for example, ensures that problem solving can be included as a subject in any discipline or cross discipline. Thus the new STEM vision for Flanders can also be applied to other disciplines. The way in which the new Flemish macro-curriculum is composed gives teachers the freedom to combine and realise goals in various ways, but also the responsibility for doing so in a consistent manner. Only in this way integrated STEM education can become a reality in Flanders.

New STEM vision in an updated curriculum

Over the past decade, various actions and initiatives have been developed to ensure that the STEM vision on education, namely ‘building scientific, technological and mathematical insights, concepts and practices (S, T & M) and deploying these for solving complex queries or actual problems (E)’, is put qualitatively into practice.

Whether all these actions and initiatives achieve their goal is still difficult to say. Nevertheless, the STEM monitor that is published by the Government of Flanders on an annual basis provides insight into the first developments that are taking place in STEM education.

Thus the proportion of those entering and graduating, and girls, in STEM study courses[28] for example, is being monitored and compared with the 2010-2011 reference year. This data is an important indicator for guaranteeing 'human capital in STEM domains'. The table below provides a concise overview of those entering and graduating since 2014.

↓ ***Figure 7:*** *Number of people entering higher education and secondary education*

Secondary and higher education (pure STEM) inflow				
	2010-2011 (reference year)	**2014-2015**	**2015-2016**	**2020 final goal**
Proportion of girls in (third grade) secondary education (%)	27.4	29.66	30.10	33.33
Proportion of STEM professional bachelor students (%)	23.82	25.57	26.25	27.82
Proportion of women in professional STEM bachelor (%)	21.13	22.54	23.634	25.20
Proportion of STEM courses in academic bachelors (%)	29.02	30.46	31.13	33.02
Proportion of women in academic STEM bachelor (%)	35.50	33.56	34.14	33.50

[28] Pure (standard) STEM = study courses in which the emphasis is clearly placed on mathematics, exact sciences, technology or ICT and the aim of which is to enable graduates to perform a scientifically and/or technologically oriented job.

Care STEM = study courses in which the finality is primarily aimed at taking care of people or animals, yet which also include a considerable number of STEM subjects (sometimes more in certain years than in others). Most graduates from these disciplines end up in the care sector.

Light STEM = study courses in which one or more years of the curriculum include a limited number of STEM subjects

Non-STEM = by exclusion, these are all other study courses

STEM (pure STEM) outflow			
	2010-2011 (reference year)	**2014-2015**	**2015-2016**
% STEM certificates in secondary education (all types of education)	43.87	43.98	44.55
% of women for the total number of STEM certificates in secondary education	29.52	31.35	31.60
% of study certificates in higher education	25.45	25.64	26.03
% of women for the total number of STEM certificates in higher education	29.43	31.29	30.88

↑ ***Figure 8:*** *Number of qualified people exiting STEM*

Based on this overview the 2012-2020 STEM Action Plan targets seem feasible and it can be concluded that the numerous actions and initiatives are bearing fruit. However, a detailed study of the report reveals that the labour market-oriented form of education in secondary education[29] warrants special attention; for both the inflow and outflow. A decrease of -1.33% for inflow and -1.58% for outflow was found in purely practical STEM (third grade) courses compared with the reference year. For higher education, there was a positive evolution of inflow and outflow across the various forms of education.

More data and detailed analyses are necessary to confirm and explain these and other evolutions in the STEM landscape. As the first results of the STEM@school research project have shown, integrated STEM education increases the motivation and interest of students. The addition of an educational goal about STEM integration in the renewed curriculum for secondary education can give an extra boost for the realisation of the targets in the action plan and so for a STEM-aligned education in Flanders.

[29] The STEM educational offering is spread over various STEM study courses that can be abstract-theoretical, theoretical-practical or purely practical.


SLOVENIA

Authors

Andreja Bačnik

Andreja Bačnik is a senior consultant for chemistry at National Education Institute Slovenia (NEIS) and Coordinator of STEM group. Her research and working areas are: Chemical (science) education, particularly active teaching and learning approaches in chemistry (science); coordination and performing of different types of in-service training for teachers (seminars, study groups, conferences); preparing and implementing new curriculum etc. She was the Slovenian expert in the Thematic Working Group on Mathematics, Science and Technology (MST) Education and PLA, Education and Training 2020, European Commission. She also represents Slovenia as National Contact Point (NCP) for Scientix.

Mojca Suban

Mojca Suban is a Senior Consultant for Mathematics at the National Education Institute Slovenia and a coordinator of the Mathematics subject group. Her work focuses on the mathematical curriculum development and its implementation in primary and secondary schools. She is leading various in-service teacher training events like seminars, workshops, study groups on contemporary didactic approaches and active teaching methods. She is the author of articles from the field of mathematics education and the editor of books and manuals for teachers. Through her work Mojca Suban emphasises both, the development and understanding of mathematical notions and concepts on one hand and the importance and usefulness of mathematics on the other hand.

Abstract

Among the knowledge, skills and attitudes (competencies) that are becoming increasingly important in contemporary society (21st century) scientific and mathematical literacy are prominent. They encourage students and teachers to engage in systemic thinking, to be scientifically and mathematically creative in new knowledge areas, to collaborate in problem solving situations, to develop self-directed skills etc.. Can these skills be developed in science and mathematics classrooms? Strong possibilities and support exist in Inquiry based education (IBE) within Inquiry Based Learning (IBL). We know that inquiry is not a new concept in education, but in the last decade it has again come into focus, has evolved and been refined. In our contribution, we will try to define inquiry based learning in broader (general) and more narrow (STEM specific) sense with formative assessment in focus. We will also touch upon the phases of inquiry-based learning and the inquiry cycle. The focus will be on implementation of inquiry based learning in Slovenia, presenting the status of IBL in Slovenian STEM curriculum and an overview of its implementation through different projects and the in-service teachers training of the NEIS. We will emphasise the advancement of IBL in science and mathematics education (STEM education) with special regards to inquiry skills.

Inquiry Based Learning in Slovenian Science and Mathematical Education

Introduction or understanding of inquiry based learning with formative assessment in focus

Educational policy bodies worldwide regard inquiry-based learning as a vital component in building a scientifically literate community (European Commission, 2007; National Research Council, 2000 in Pedaste et al., 2015).

Contemporary expert discussions about knowledge and skills for 21st century encourage students and teachers to develop scientific and mathematical literacy (within that the ability to deal with missing information and to be scientifically and mathematically creative in new knowledge areas) and systemic thinking. The ability to collaborate in problem solving situations and to communicate results with interpersonal and self-directed skills is also emphasised (Partnership for 21st century skills, 2007).

One of the most quoted and referred tools or approaches for reaching such knowledge and skills in education (especially in STEM area) is Inquiry based education (IBE) within Inquiry Based Learning (IBL). Inquiry is not a new concept in education. It has roots in the studies of Piaget (1929) and the insights of Dewey (1933) and Vygotsky (1978) among others, which revealed the important role of children's curiosity, imagination and their urge to interact and inquire in their learning (Harlen, 2014).

If we look at the terminology from the area of inquiry education, we find many different variations of definitions, depending upon the width and depth of the view onto inquiry. However, all definitions have in common that IBE/IBL is student oriented and within inquiry, students are learning by questioning and investigation, developing high-order skills to reach new knowledge with understanding and working in ways, similar to those of scientists and mathematicians.

Abbreviations from the area of inquiry education within STEM are presented in Table 1:

Science Education	Mathematics Education
IBE - Inquiry based education	
IBSE - Inquiry based Science education	**IBME** - Inquiry based Mathematics education
IBSME - inquiry-based science and mathematics education	
IBA - Inquiry-based Approaches	
IBL - Inquiry Based Learning	
IBSL - Inquiry Based Science Learning	**IBML** - Inquiry Based Mathematics Learning
IBT - Inquiry Based Teaching	
IBST - Inquiry Based Science Teaching	**IBMT** - Inquiry Based Mathematics Teaching

↑ ***Table 1:*** *Abbreviations from the area of inquiry education within STEM*

The terminology of inquiry education has evolved throughout the years and the concepts were refined. Nowadays the Inductive Approach is often referred to as **Inquiry-based Science Education (IBSE)**, mostly applied to science of nature and technology on one hand and **Problem-Based Learning (PBL)** in mathematics on the other (EU: Science Education Now: A renewed Pedagogy for the future of Europe, 2007). The IBE terminology has been gradually spreading from the science education to mathematics education in the last period and the term **Inquiry-Based Mathematics Education (IBME)** is nowadays widely used.

IBL as an inductive approach leaves more space for observing, experimenting and self-constructing of knowledge (bottom-up approach). By definition, inquiry is the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments (Linn Davis, Bell, 2004 in EU: Science Education Now: A renewed Pedagogy for the future of Europe, 2007).

Nowadays the term **Inquiry Based Learning (IBL)** is widely accepted and mostly referred to as a way of teaching and learning science and mathematics in which students are supposed to proceed in the way scientists and mathematicians actually work (Primas, 2013).

Inquiry-based Science and Mathematics Education (IBSME) (Fibonacci, 2013) goes beyond the learning of concepts and basic manipulation to the key factor of engaging students in identifying relevant evidence and reflecting on its interpretations. Through IBSME:

- *Students develop concepts that enable them to understand the scientific aspects of the world around them through their own thinking, using critical and logical reasoning about evidence that they have gathered.*
- *Teachers lead students to develop the skills necessary for inquiry and understanding of science concepts through their own activity and reasoning.*

Barron and Darling-Hammond (2010) even speak about **Inquiry-based Approaches**, which include project based learning, problem based learning and learning through design. Students need opportunities to develop higher-order cognitive skills, which can be developed through Inquiry-based approaches in complex, meaningful projects that require sustained engagement, collaboration, research, management of resources and development of an ambitious performance or product.

Inquiry based education/learning (IBE/IBL) is a tool and a goal; it is a process and a product at the same time (Krnel, 2007). It is strongly connected with **Scientific and Mathematical literacy**.

For example, scientific literacy requires not only knowledge of the concepts and theories of science but also knowledge of the common procedures and practices associated with scientific inquiry and how these enable science to advance.

Therefore, individuals who are scientifically literate have knowledge of the major conceptions and ideas that form the foundation of scientific and technological thought; how such knowledge has been derived; and the degree to which such knowledge is justified by evidence or theoretical explanations (PISA 2015 draft science framework, 2013).

We can understand IBL in a broader (general) and narrower (specific) sense

IBL in a broader (general) sense is part of various didactic (teaching) approaches and strategies, including problem-based learning, project work, cooperative learning, experimental work etc. These approaches have the following characteristics in common:

- *they are based on the constructivism: through various activities, students independently discover natural laws and come to new conclusions, thereby broadening their knowledge, developing their thinking and deepening their understanding of the chosen concepts; they reflect a view of learning as a social and collaborative activity…*
- *the stress of activities lies on developing process skills (lifelong learning skills)*
- *the emphasis is on students as active problem solvers as they tackle issues that they find interesting or relevant (they are included in all stages of a task/project, from planning to execution)*
- *students take over responsibility for their own achievements and results*
- *the role of teachers is changed into the role of advisers and motivators*
- *frequent student-teacher interactions*
- *the social context of learning is emphasised (cooperative learning, team working etc.)*

If we understand IBL in such a broader sense, we find accordance with formative assessment. Considering five key strategies of formative assessment (Wiliam, 2010) we can realise that quality IBL could not be proceeded without formative assessment:

1. *Clarifying, sharing and understanding learning intentions and criteria for success.*
2. *Engineering effective classroom discussions, activities and tasks that elicit evidence of learning.*
3. *Providing feedback that moves learner forward.*
4. *Activating students as instructional resources for one another.*
5. *Activating students as owners of their own learning.*

The ideas of IBL and formative assessment are closely related; they intersect and intertwine in more ways:

- *Students are at the heart of the learning process.*
- *They play an active role in the process of acquiring new knowledge and they are in charge of that process.*
- *They ask questions and discuss their ideas with peers by giving feedback.*
- *They are involved in the planning process: for example by giving suggestions for the inquiry.*
- *Students build their knowledge on what they already know.*

The key feature of IBE is using ideas and inquiry based approaches not only occasionally but as adopted and predominant ways of teaching and learning (Artigue, Blomhoj, 2013 in Suban, 2017).

If we consider teaching mathematics, IBMT is 'a teaching approach that allows students to be engaged in an activity which leads them to adapt their existing or construct new, mathematical knowledge' (Winsløw et al., 2017).

If we look upon IBL in a **narrower (STEM- specific) sense**, we can ascertain that the emphasis is on understanding of scientific research and on systematic development of scientific inquiry skills, needed for scientific research. In IBSL the role of experiments is very important (lat. experimentum from lat. experiri — to experience, try, examine) as a scientific procedure and the foundation of science education. Through experiments, students learn about the basic science concepts and phenomena, deepen their understanding, integrate knowledge, and develop their experimental research skills. Experiments are used to establish inquiry (research), prove, confirm or reject hypotheses or theories (Bačnik et al., 2016).

The IBSL/IBML is a process in which students are invited to work in ways similar to how mathematicians and scientists work (Encyclopaedia of Mathematics Education). This means they have to:

- *observe phenomena,*
- *ask questions,*
- *look for mathematical and scientific ways of how to answer these questions (like carrying out experiments, systematically controlling variables, drawing diagrams, calculating, looking for patterns and relationships, and making conjectures and generalizations),*
- *interpret and evaluate their solutions,*
- *communicate and discuss their solutions effectively.*

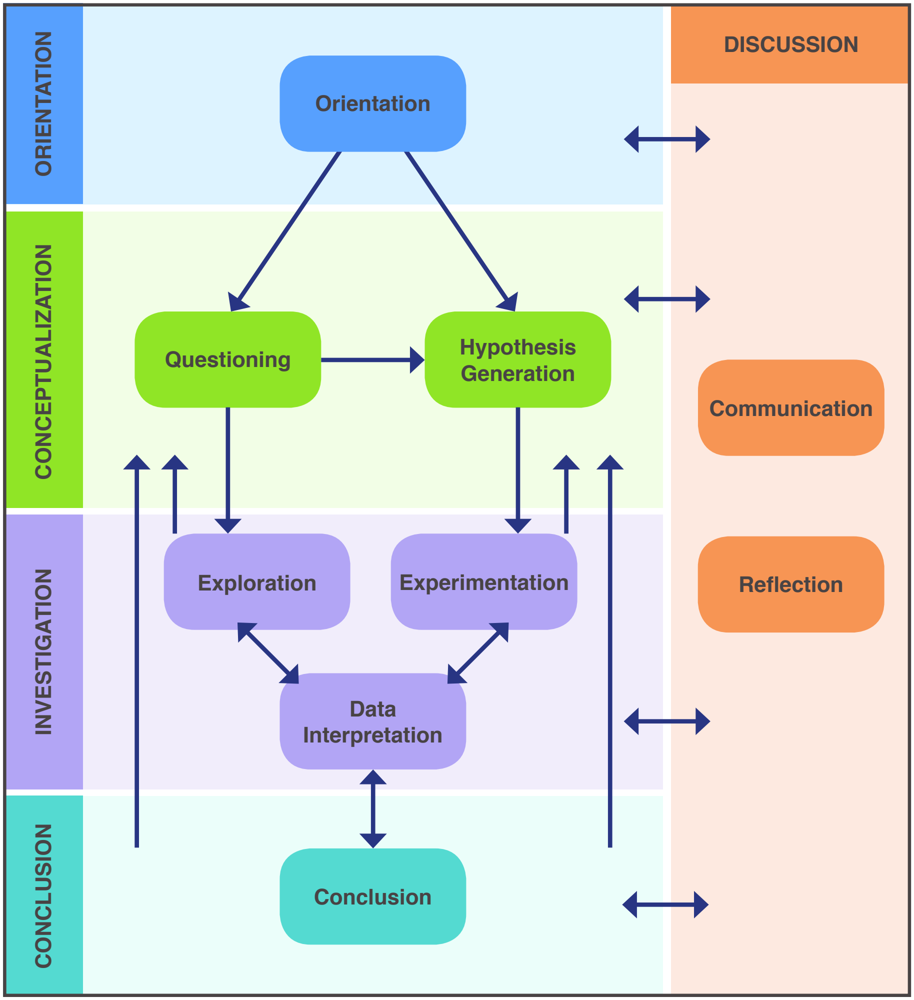
Concerning IBML, inquiry can loosely be defined as "investigating a problem". Here, the word "investigate" implies that the efforts to solve the problem are relatively autonomous: not directed by others and not following a prescribed routine method (Meria, 2017).

Phases of inquiry-based learning and inquiry cycle

Inquiry-based learning is often organized into inquiry phases that together form an inquiry cycle.

Pedaste et al. (2015) analysed 32 articles describing the whole inquiry cycle. The analysis of the articles resulted in the identification of five distinct general inquiry phases: Orientation, Conceptualization, Investigation, Conclusion and Discussion as shown in the picture 1.

↓ ***Picture 1:** Inquiry-based learning framework (general phases, sub-phases, and their relations), (Pedaste et al., 2015)*



A more detailed explanation of the phases and sub-phases of the synthesized inquiry -based learning framework is shown in table 2.

Phases and sub-phases of the synthesized inquiry-based learning framework			
General phases	**Definition**	**Sub-phases**	**Definition**
Orientation	The process of stimulating curiosity about a topic and addressing a leaning challeng through a problem statement.e		
Conceptualization	The process of stating theory-based questions and/or hypotheses.	Questioning	The process of generating research questions based on the stated problem.
		Hypothesis Generation	The process of generating hypotheses regarding the stated problem.
Investigation	The process of planning exploration or experimentation, collecting and analysing data based on the experimental design or exploration.	Exploration	The process of systematic and planned data generation on the basis of research question.
		Experimentation	The process of designing and conducting an experiment in order to test a hypothesis.
		Data Interpretation	The process of making meaning out of collected data and synthesizing new knowledge.
Conclusion	The process of drawing conclusions from the data. Comparing inferences made on data with hypotheses or research questions.		
Discussion	The process of presenting findings of particular phases or the whole inquiry cycle by communicating with others and/or controlling the whole learning process or its phases by engaging in relective activities.	Communication	The process of presenting outcomes of an inquiry phase or of the whole inquiry cycle to others (peers, teachers) and collecting feedback from them. Discussion with others.
		Reflective	The process of describing, critiquing, evaluating and discussing the whole inquiry cycle or a specific phase. Inner discussion.

↑ ***Table 2:*** *Phases and sub-phases of the synthesized inquiry-based learning framework, (Pedaste et al., 2015)*

The inquiry process follows phases and sub-phases which can have different foci in different age groups. Advancement in inquiry skills and understanding of the scientific way of thinking and acting is possible through different levels of inquiry. In younger years, students make the first steps into inquiry process. By advancing through the educational vertical, the inquiry cycle becomes more complex and coherent gaining in quantity and quality. The phases or sub-phases of the inquiry process can be supported by questions, which differ according to the age of students. For example in Table 3, we present a vertical approach by means of questions connected to the setting and controlling of the variables as a part of sub-phases "Exploration" and "Experimentation. "

↓ ***Table 3:*** *Vertical approach via questions connected to the setting and controlling the variables*

<table>
<tr><th colspan="3">Setting and controlling of the variables</th></tr>
<tr><td>1. level
(students aged from 6 to 9)</td><td>2. level
(students aged from 10 to 14)</td><td>3. level
(students aged from 15 to 19)</td></tr>
<tr><td>What will I change?

What stays the same all the time?</td><td>What can be changed in the experiment?

What will I track?

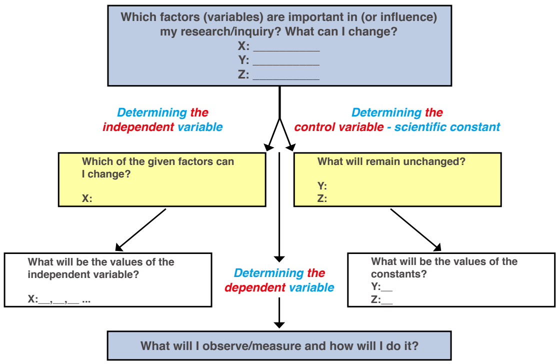
What will I change/keep unchanged?

What will I observe or measure?

What can be changend in the experiment?
....
I will change:
....
I will keep constant/unchanged:
....
How will I determine the effects? What will I measure or observe?
....
....</td><td>Which variables influence the observed phenomena?

Which are dependent and which are independent variables based on the research question?

Which variables are necessary to control?


</td></tr>
</table>

What is the status of IBL in Slovenian STEM curriculum, how is it implemented through different projects and in in-service teacher trainings of National Education Institute Slovenia (NEIS)?

It is of great importance that the national curricular documents support IBL clearly and consistently in order to make changes in the teaching practice. Science and mathematics (STEM) curriculum in Slovenia (2008, 2011) supports a systematic and vertical approach to IBL. Curriculum, as the basic document for teachers' lesson planning, opens many possibilities for the implementation of IBL through different activities and projects.

A far as Slovenian science and mathematics curriculum is concerned, the inquiry dimension is clearly visible through:

- *general goals and competencies*
- *didactic recommendations*
- *specific content and process goals (for example during an inquiry project).*

As an example, we could mention the specific chapter in the mathematics curriculum called Mathematical problems and problems from everyday life situations that is included in each class to insure the vertical approach. The chapter is focusing on problem solving (open and closed problems), combinatorial situations, modelling, investigating patterns, etc. The inquiry based approach is recommended.

Inquiry across the curriculum in science and mathematics helps students to internalize a process for inquiry that is transferable to everyday life situations. A systematic approach to inquiry is essential for the development of inquiry skills to prepare students for problem solving and life learning. It ensures that students have the opportunity to engage in inquiry, to learn an overall process and to understand that this general inquiry process can be transferred to other inquiry situations. Inquiry based learning enables students to:

- *develop skills they need all their lives*
- *learn to cope with problems that may not have clear solutions*
- *deal with changes and challenges connected with understanding concepts and processes*
- *shape and build their strategies for dealing with new challenges*
- *learn to collaborate with peers*
- *ask relevant questions*
- *recognise the role of science and mathematics in everyday life situations.*

Systematic approach to IBL, which is in the core of curriculum, demands certain changes in the teaching practice. The shift from traditional to inquiry based teaching practice seems to have many implications from students' and teachers' point of view. We tried to point out some of the implications of those two approaches to teaching practice in Table 4, but we are well aware there is no such clear distinction between them. For the purpose of this article we used this "black and white picture" to raise awareness about the necessary changes in teaching practice when using IBL approach.

Traditional teaching practice	Inquiry based teaching practice
Teacher provides **all the information.**	Teacher is **a facilitator** and **moderator** of the learning process.
Knowledge comes in **made packages.** **Established facts** are presented.	**Knowledge is constructed** in the inquiry process by a student.
Students' learning is focused on **content knowledge.**	Students **learn the skills of inquiry.**
Different questions can occur.	**Open and diverse questions** are systematically encouraged.
Responsibility of the learning process is mostly on teachers' side.	Students take **more responsibility** for their own learning.
Students listen and make notes.	Learning also takes place **in pairs** and **small groups**.
The awareness of systematic development of high level cognitive skills is not in focus.	**Higher level cognitive skills** are important and developed.
Teacher is the **primary source of knowledge.**	**Different sources** are used in the process of inquiry.
Finding **the right answer** is important.	Seeking the appropriate resolutions to problems is in focus, **the process** is more highly valued rather than just the right answer.
The problems are often presented in **closed way**.	Problems are often presented in an **open way**.

↑ ***Table 4:** Traditional vs. inquiry based teaching practice*

Vertical approach to IBL is another component of the curriculum that plays an important role in teaching and learning practice. Students gradually build and develop their inquiry skills from the kindergarten up to pre-university education. They become more and more familiar with the inquiry process and they integrate and supplement the necessary skills. The inquiry learning cycle seems to be repeating in a 'helix like' way for building new quality with each repetition. Upgrading each of the inquiry skills during the students' progress through educational vertical enables them to understand a framework that supports inquiry process (see Table 3). They also internalize inquiry skills for individual and group use and adapt procedures to various inquiry situations.

In Slovenia, we try to build a culture of inquiry throughout the entire education system i.e. across the whole curriculum by supporting systematic, vertical, integrated, cross-disciplinary approach to inquiry. However, reaching the goal of vertical culture of inquiry represents a big challenge, since we need:

>

- *stronger support of curricular documents (more visible systematic, vertical approach etc.),*
- *good support of pre-and in-service teacher trainings and*
- *determination and support of educational policy, which should be recognised in the national strategy for STEM education.*

The NEIS have been involved in several **national and international projects and initiatives** that were/are strongly related to IBL (IBSL and IBML). It worked on IBL in international projects like Scientix 2, EU-folio, ATS 2020 and currently we are active in the MERIA project, Scientix 3 and CIDREE initiative for the encouragement of IBL. At national level, we strongly addressed IBL in the development tasks/projects like flexible curriculum, formative assessment, didactical renovation of school practice, innovation projects. Currently we are leading a five-year large-scale national project, developing scientific and mathematical literacy.

During the last decade, NEIS and other institutions carried out a large number of various STEM **teacher trainings** connected to IBL. However, the impact of teacher training on IBL is not very clear. There are different practices detected in the Slovenian schools that encourage IBL. Some teachers have excellent examples of practices for implementing IBL and they are willing to share their experiences. There has been no overall national survey examining the quality of IBL and the extent to which it has found its place in our classrooms.

Next to the NEIS there are also other institutions like universities and different research institutes that provide pre-and in-service teacher trainings related to IBL (for example the Pedagogical Faculty of Ljubljana was involved in the Primas and Profiles projects etc.). However, there seems to be no strong and clear connection and consistency between all the institutions regarding the IBL implementation, which is partly the consequence of a missing strategy for the science and mathematics education in Slovenia.

Conclusion

Throughout the scientific literature, there are many different definitions of Inquiry based education/learning (IBE/IBL) but they all have in common that IBL is a student-oriented approach. Within inquiry learning, by questioning and investigation, students develop high-order skills, acquire deeper knowledge and try to work in ways similar to how scientists and mathematicians work. There seems to be no doubt that the IBL paradigm is an efficient teaching approach for developing the 21st century skills. In Slovenian schools, the IBL ideas and practices have been gradually implemented and developed through various national and international projects in the last decade. Our teachers report on benefits of IBL in the classroom in connection with formative assessment like:

- *students are becoming more active (taking over responsibility for their learning)*
- *students are more connected within the classroom (more discussion, etc.)*
- *knowledge seems to be more flexible and deepened, etc..*

The national STEM curriculum supports and encourages the IBL approach but we are still facing some challenges in practical implementation of inquiry culture. These are: even stronger support of curricular documents, improved support of pre-and in-service teacher trainings, teachers' personal-professional challenges and above all determination and support of national policy, which could be acknowledged in strategies for STEM education in Slovenia and which still have not been developed.

Most of the findings in this paper are more or less just empirical and a more systematic and nationwide survey would be needed. Collaboration with other institutions could be more systematic, more consistent and stronger in terms of IBL implementations and connecting with the research community. Schools in Slovenia have an excellent opportunity for systematic vertical development of inquiry skills due to a 9 years basic education where all the students aged from 6 to 14 are located in the same building. This enables collaboration between students and teachers on a daily basis. The challenge is also the transition to upper secondary education. However, building a culture of Inquiry Based Learning (IBL) in Slovenian schools, especially in STEM education should no longer be an option but an imperative for all parties involved.

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Authors

Mária Szabó

Mária Szabó is a teacher of biology and chemistry, who has been working as a research fellow at the Hungarian Institute for Educational Research and Development at the Eszterházy Károly University in Budapest for 15 years. Her professional interests are school leadership and school development. She is the professional leader of the Student Voice project, realized with the cooperation of 5 different countries. She participated in several national and international school development projects and she has experience in curriculum development. Currently she is responsible for the curriculum development of natural science in vocational secondary education in Hungary.

She is involved as a lecturer and a programme developer in the training of school leaders, run by the Hungarian-Netherlands School for Educational Leadership and Management.

Atilla Varga

Attila Varga, PhD is a psychologist and biology teacher. He is currently a senior researcher and team-leader at the Hungarian Institute for Educational Research and Development at the Eszterházy Károly University. His main interest is school-development and education for sustainability. He has co-ordinated the development of the network of Eco-schools in Hungary for the last ten years. He is responsible for the development of educational programs for all-days schools. Beside his development work he also give lectures on psychology and education for sustainability and environmental awareness at several Hungarian universities.

Authors

Andrea Pallag

Andrea Pallag is a textile designer and art teacher, who has been working as a researcher at the Hungarian Institute for Educational Research and Development at the Eszterházy Károly University. Her professional interests are art education and school development. She is experienced in curriculum development, school research and development; aiming for subject integration in an interdisciplinary way and looking at several ways to promote advanced art education. Besides her research and development work, she is an associate professor of Moholy-Nagy University of Art and Design, in the Department of Pedagogy and Psychology, where she supports the development of trainee art teachers in innovative methodologies.

Melinda Filó

Melinda Filó is a Psychologist and an Art Therapist who has been working as a Pedagogical Development Officer at the Hungarian Institute for Educational Research and Development at the Eszterházy Károly University in Budapest. She is responsible for running the pilot of the Finnish 'KiVa' anti-bullying project in Hungarian primary schools, supporting the school staff and delivering trainings to them. As an Art Therapist she mainly works with children with social, emotional and behavioural difficulties and with difficult family backgrounds. In the past she has worked with clients who suffered from bereavement, attachment difficulties, disability, substance misuse, domestic violence, sensory impairment, Tourette Syndrome, sexual and physical abuse, dementia and HIV/AIDS. She also worked with refugees and Young Carers in the UK, in Malaysia and in Hungary.

Abstract

Hungarian political, economic, cultural and even educational life is characterized by the dualism of the tradition and the modernity. This paper sheds some light on this Hungarian feature in the field of education. It summarizes the political and professional activities, related to the challenges of an information-based and highly technological society, which requires much higher-level capabilities in STEM and science literacy from students than what was considered acceptable in the past.
The Hungarian ministry of education is aware of the importance of not only STEM, but the importance of arts education, too. This is declared in the Strategy for the Development of Public Education (Köznevelés-fejlesztési stratégia in Hungarian), but there is no action plan connected to this, yet. Nevertheless, several top-down and even bottom-up initiatives can be found in the system with the aim of improving the STEAM (Science, Technology, Engineering, Arts and Mathematics) education in Hungary. This paper tries to give an overview of the results and obstacles of those activities. The authors hope that the readers can get a sense of the tension between the traditional and modern paradigms in education, as well as between the requirements of the employers and the possibilities for the schools. We point out some obstacles for disseminating the results of different projects in the field of the inquiry-based learning. A short analysis of some good examples for cooperation between schools and other actors of the society are given in the next part of the paper. Lessons and some suggestions conclude the article.

The Hungarian 'STEAM ENGINE' – Schools and Social Partners for STEAM Education

Introduction

Hungary is a Central European country with the roots of its education system going back to the Austro-Hungarian monarchy and the memory of the socialist regime. The country has been a member of the EU since 2004 and was the originator of the V4 cooperation. These facts influence the political and everyday mentality of the people as well as the educational system.

In connection to the EU 2020 recommendations, the improvement of science, technology, engineering, arts and digital literacy is the focus of the national educational development strategy[1]. Enforcing environmental sustainability considerations is a transversal requirement for the improvements.

Tradition and modernism are relative concepts. Nearly 200 years ago, Stephenson's steam engine, moving at 4km/h speed over iron rails, was a technical sensation, and became a symbol of the industrial revolution in the 19th century. It had great influence on several aspects of life but it was dangerous and polluting. In contemporary technological society the steam-engine, running on the iron rails symbolises the past. But we should keep in mind that the steam engine itself (and not the steam locomotive) is the central element of the power generation even today. So it can be a symbol of the connection between the past and the future.

↑ ***Picture 1:*** *Changes in traffic in the word (The Rocket, 1829, one of the first steam engines in the world and JR-Maglev MLX01, Japanese magnet-train, which reached 581 km/h speed in2003. (How many similarities and differences can you find in the two pictures?)*

[1] *Köznevelés-fejlesztési stratégia, 2014*

This technological change has influenced everyday life, as well as schools. Education in Hungary presents the same duality. It tries to answer to the challenges of the 21st century with methods from the 19th century. In most of the schools the structure of education and the teaching style only changed a little, while our knowledge about the process of learning has developed dramatically. This article intends to introduce the readers into the multi-level process that aims to prepare our young people for the challenges of the 21st century. This is undertaken by an overview of the strategic purpose and the presentation of elements of activities. The writers hope, that by the end of this paper the readers will understand a bit more about the metaphor of the Hungarian STEAM Engine in the title.

↑ **Picture 2:** *Classrooms in the beginning of the 20th and of the 21st century in Hungary. (How many similarities and differences can you find in the 2 pictures?)*

The situation of Science and Arts education in Hungary

Hungary has a selective education system, where basic education (ISCED I) is the first period of the 8-grade elementary school (ISCED I + ISCED II). Three types of secondary schools (ISCED III) are connected to elementary education. (1) Secondary Grammar Schools traditionally provide a high-level general education for their students so they can continue their careers in higher education. (2) Vocational Secondary Grammar Schools provide training for jobs and the possibility for further professional education for their students at the same time. (3) Secondary Technical Schools provide vocational training for their students.

Natural Science is taught as part of an integrated subject in the first six grades of compulsory education (the age of 6 to 12) and it is divided into four separate subjects (Biology, Chemistry, Geography and Physics) from the 7th grade on. The system is the same at Secondary Grammar Schools, but at Secondary Technical Schools a complex subject (Science) is taught in the 9th grade. In the next three grades students learn one or two separate subjects on Natural Science (Biology, or Chemistry, or Physics, or Geography), depending on the type of Secondary Technical School. Secondary students have achieved good results in the International Science Olympics in Physics, Chemistry and Biology for decades. Talented Hungarian students achieve good results in the International Junior Science Olympics (IJSO), a competition organized into groups of six students, younger than 16.

The country has been participating in the TIMSS tests since 1968 and in PISA tests since its beginning. In the TIMSS tests, which focus on subject knowledge, Hungarian students have produced good results (above average and they were among the best in the group of European countries). In contrast, in the PISA tests, that focus on problem solving capabilities and monitor the knowledge-application competencies, Hungarian students have been producing significantly lower results than in the TIMSS tests. In the PISA 2012, the Hungarian students' results were lower than the average of the OECD countries and in mathematics 28,1% of them could not even reach the second level. The continuous decrease of mathematics and science results has happened between 2000 and 2012. From these subjects 'by the end of the elementary school (ISCED 3) Hungarian students know less than 10-15 years ago.' (Csapó et al, 2014:133).

In this situation, the Hungarian education ministry is aligned with the targets mentioned in Europe 2020, which aim at improving creativity and increase interest in natural sciences and mathematics and widen knowledge and skills of the students in these fields (European Commission, 2010). The Hungarian education policy thinks that the declaration of the new content regulation, which concentrates on the complex development of students' personality and their knowledge, is in harmony with the priorities and frames of the Europe 2020 Strategy. The Hungarian strategy for public education emphasises the need for complex educational programmes in the field of natural sciences, mathematics, arts and entrepreneurship. The document specifies some interventions, aiming to reach this target. The complete realization of the so-called knowledge triangle of education, research, and innovation is one of the planned interventions, such as the realization and support of the network-based work culture. To support the connection-building between teachers of different natural sciences and between the worlds of research, science and work and supporting STEM education are priorities in the education strategy.

Mainly funds from the European Union are allocated to realize these strategic priorities. Market actors and some NGOs have been participating even in public education to support the realization of the needs of the employers, mentioned in the Europe 2020 Strategy.

Visual culture, music and songs are the main subjects of the art education at Hungarian schools. Art lessons are limited, but in general education all students deal with art in some way up until the age of 18. Even a graduation exam can be taken from a chosen art subject. Students with special interests or abilities in any kind of arts (e.g. fine arts, instrumental music, folkdance) can participate in special form of art education (basic art education school) in extra lessons. Talented students can choose different types of art secondary schools from the age of 14.

The Hungarian teachers are generally trained for two different subjects. In the field of the natural sciences it means that teachers have different combinations of degrees in Biology, Chemistry, Geography, Mathematics and Physics. In practice this varies, because of the system of teacher training colleges, where some other combinations can be chosen.

The system is similar in art teaching. Most of the art teachers have a MA teaching degree in the specific art subject (such as Visual culture, or Music and songs), but some teachers have a degree relative to two different subjects (Mathematics and Visual arts, or Geography and Visual arts). These combinations give a great possibility to handle the natural phenomena in a complex way. In secondary education, and especially in the vocational secondary grammar schools specialising in arts, a special artist diploma (MA) plus a teacher degree are required to teach arts.

Strategic activities to improve STEAM

Although there is no existing action plan to implement the educational strategy, several interventions have been launched in the last couple of years in Hungary in order to improve the situation. The main elements of them are summarized in this chapter.

Top-down interventions

Although the literacy on the innovation (Fazekas & al., 2017.) emphasises the importance of the connection between the top-down and bottom up innovation processes, it is not easy to define the directions of different innovation or developmental processes. We consider top-down interventions those processes, which are initiated on national level and strongly connected to the implementation of the education strategy.

The Strategy for Public Education emphasises the importance of the development of creativity, which is the basis of the economic innovation. It says that this is connected to the enhancement of general interest in natural sciences and mathematics, as well as the deep knowledge and competencies in these subjects. To achieve this objective, the Strategy mentions those complex educational programmes, which focus on the complex improvement of the personality and knowledge of the students and deal with school life as a whole. It means that the schools have to realize these programmes not only on the level of lessons, but also in the time during which students are at schools, outside the classroom. (They are called whole-day school programmes.) The Strategy gives a priority to the improvements of complex educational programmes in the field of natural sciences, engineering, arts, digital literacy, environmental sustainability, and practical life. The decreasing number of well-prepared teachers in the field of arts and natural sciences could hamper the planned improvements.

The elements of the content regulation could be regarded as tools for the implementation of the strategy. Hungary has a National Core Curriculum (NCC) which is compulsory for each actor (public schools, private schools, teachers, parents and students) of the whole education system. The actual NCC (revised last in 2012) contains not only the principles, overall goals, development tasks, and key competencies which have to be developed, but also the specific aims, learning outcomes and the learning content of the subjects in 10 different areas of cultural domain. The huge amount of learning content hinders the personal development of students.

Several national programmes have been launched to support different elements of the STEAM education and the development of talented students. One of these was the *Öveges Programme*[2], named after a famous teacher of physics, József Öveges. He was famous for making physics more popular and was involved in training physics teachers in the middle of the last century. The overall target of this programme was to renew the methodology and the toolkit of teaching natural sciences in public education. It was co-financed by the budget of Hungary and the European Social Fund, and was launched in 2013. Schools could apply for grants to build appropriate laboratories for teaching physics, chemistry and biology, which can accommodate the students and teachers of several schools. They had to develop programmes for students from different schools in these modern laboratories, to provide a possibility for the experimental and joyful learning in different subjects of natural sciences.

[2] *https://www.palyazat.gov.hu/doc/3368*

The *Hungarian Eco-School Network* was established in 2000 with 40 pilot schools based on the whole-school approach of the ENSI network and has continuously been increasing since then. Since 2005 Eco-School title in Hungary serves the highest governmental recognition of those schools that deal with the practical realization of education for sustainable development (ESD) in a carefully considered, institutional and systematic way. The Green Kindergarten network joined the school network in 2006 and the two networks have been side-by-side since then. At present the networks have almost 2000 members, approximately the quarter of all Hungarian pre-primary, primary, secondary and vocational schools are involved in them. Institutions could join the networks on a voluntary basis by applying for the Eco-School title. (OFI, 2010) (Réti, Horváth, Czippán, & Varga, 2015). An Eco-School and a Green Kindergarten differ from an average school and kindergarten in the sense that the principles of sustainability are present not only in education but in all aspect of the life at the institute. Local environmental issues and problems are mainly dealt with priority in their pedagogical work.

The criteria systems of the networks support the STEAM education in many ways:

- *Cross-curricular and real life activities are promoted.*
- *Collaboration with social partners, research institutions, and artists exist in the life of a Green Kindergarten, Eco-School.*
- *STEAM focused joint activities, like team competitions, meetings, festivals, camps are organized for institutions.*
- *In-service teacher training activities (like trainings, conferences, workshops) of the networks often contains STEAM related elements*

Supporting the development of talented students is a priority of the education policy in Hungary. *The National Talent Programme*[3] was launched to support achieving this goal in 2008. The aim of the programme is to find, recognize, support, and develop Hungarian talents not only in Hungary but in areas beyond Hungarian borders, too. With establishing the National Talent Programme, the Hungarian Parliament gave an opportunity for a long-term, continuous and safe support for talented young people in the period from 2008 to 2028 for 20 years. A wide range of institutions (public schools, universities, NGOs) can apply for grants. Experts emphasise the importance of the continuous support, the collaboration with families (Balogh, n.d.), and the power of the networking (Csermely, 2006). All of these tasks require schools to work as learning organisations.

[3] *http://www.emet.gov.hu/hatter_1/nemzeti_tehetseg_program/*

Bottom-up interventions

In this paper the authors consider bottom-up interventions the developmental activities, where the realization of the aims is heavily built on the cooperation with practitioners (schools and teachers). A few Hungarian schools could participate in those international projects, which aimed at improving the science literacy of the students. SAILS[4] (Strategies for Assessment of Inquiry Learning in Science), or the PRIMAS[5] (Promoting Inquiry in Mathematics and Science Education Across Europe) projects supported the STEM education by using the inquiry-based learning method at both primary and secondary levels across Europe.

A unique national curriculum development activity was launched in September 2016. The title of the programme (Let Us Develop Together!) refers to the methodology of the curriculum development process. It was an initiative from the education government to support teachers' realization of the syllabus of a new subject (Complex Science) for the 9th grade of the vocational secondary grammar schools. The process of curriculum development has been led by the Hungarian Institute for Educational Research and Development (HIERD) and was supervised by a board, where the Hungarian Academy of Sciences, the Ministry of Education, three different teacher training universities, the Chamber of Teachers, and two professional associations in science are represented. The process was realized in a strong cooperation with professional programme developers and active teachers. (Szabó & Varga, 2017)

[4] *http://www.sails-project.eu/*

[5] *http://www.primas-project.eu/*

Good practices for cooperation with non-governmental actors

The good practices, mentioned below, can be put into two categories based on the programme host. (1) Those programmes, which have been initiated by a higher education institution with a teacher training profile, and (2) which have been initiated by a profit-oriented agent, or an NGO, connected to that.

Research and Innovation initiatives of higher education

PRIMAS was an international project within the Seventh Framework Program of the European Union (2010-2013). Fourteen universities from twelve different countries have worked together over four years to promote the implementation and use of inquiry-based learning in mathematics and science. PRIMAS has developed materials for direct use in class and modules for professional development (PD modules) of teachers. In addition, professional development activities and supported professional networks of teachers run in each of the partner countries. PRIMAS has also worked with stakeholders such as policymakers, school leaders and parents to create a supportive environment for inquiry-based learning. Hungary has participated in PRIMAS project with the coordination of the University of Szeged (SZTE). It was a research project and a dissemination activity at the same time, aiming at the promotion of research-based learning; and the strategies for assessment of inquiry-based learning in Science (SAIL). Hungarian participants have developed seven modules (Inquiry-based learning, Handling unstructured problems, Concept learning in inquiry-based learning, Questions that promote inquiry-based learning, Cooperative learning, Building on what the students already know, and Self-and peer evaluation) to support professional development of teachers. As a result of these projects, the present task of the SZTE Science Education Research Group is to prepare learning support tools for public education. They aim to develop scientific thinking by strengthening active learning perspectives.

Moholy-Nagy University of Art and Design Budapest (MOME) is one of the most significant Hungarian institutions of visual culture due to its traditions and intellectual background. In its effort to visualize its professional concepts, MOME compounds its own character and traditions with the most up-to-date trends. It is a university which educates professional designers on the one hand, and an intellectual workshop with the aim of setting up creative process in order to enhance design consciousness in Hungary on the other hand.

Several activities (research projects and educational programmes) of design and STEM has been existing at MOME.

The Digital Craft Lab[6] is a community for research and development. It makes a connection between the visual arts, design and other sciences. It has three different types of activities. (1) Members of the community make research in the field of the digital object-building technologies, reflecting to the radical new challenges of the new technologies and smart materials in the field of planning methods. (2) While recently the material-research and the material-experiments are in the focus of contemporary design, they make innovative experiments on coupling of materials. (3) On the basis of the experiences of the new technologies, the new craft, and the 21st century design they organise different, experience based learning programmes for schools. These programmes can support the education of STEM (Science – Technology – Engineering – Mathematics) education with the topics and methodologies of art &craft &design. So STEM can transform to STEAM.

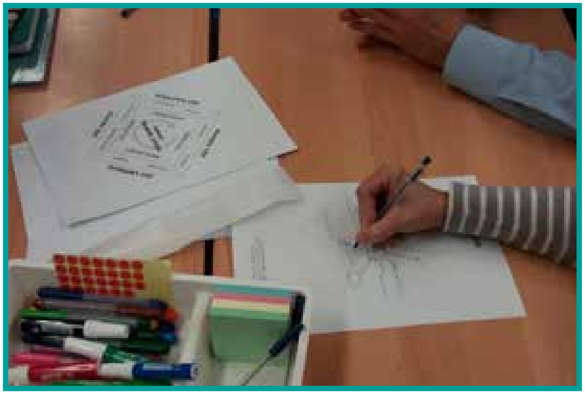
The title of the educational programme of the Digital Craft Labour is ‘Be STEAM!’. The main target of this programme is to develop a methodology that can generate the fusion of knowledge sharing, can transfer modern educational contents, and can integrate them into public education. It should be inquiry based, so can contribute to the complex and procedural knowledge building. Creative problem solving and ICT-based solutions are in the focus of this programme. Playful exercises give possibility for the development of the participants by the integration of creative object construction with the STEM contents in this programme. Cooperation, communication, development of drawing skills, and the theoretical and practical knowledge of the digital object-creating technologies have special focus in the programme.

In the ’Be STEAM!’ programme university students and lecturers create an education programme mainly for elementary schools. They try to cooperate with schools in different ways. Some elements of the visual based programmes can be used in the lessons of different subjects (such as mathematics, informatics, or natural sciences). These learning modules can support the teachers of different subjects. The activities prepare the next step of the education process, when in studios, offered by the university, children can produce visual works, using different object-creating techniques. Four different actors (the university lecturer, the teacher of an elementary school, the university student, and the children of elementary school) work together in this complex learning process. There are positive experiences with this practice. The cooperation has a positive influence and triggers a motivation to active learning in all partners. The object creation gives elementary school students the feeling of success and with it joy. Beside the positive experiences, some troubles were detected. Time management, organisation of the different activities, providing the makings (materials and tools) are the most common of them.

[6] *http://digitalcraftlab.mome.hu/hu/*

↑ **Picture 3:** *Be STEAM! School trial*

A pedagogical research and development activity has been running in the framework of the teacher training activities at MOME, which consumes design thinking as a tool for developing problem-solving thinking. The HEAD Programme is a holistic (H), cooperation based (EA in Hungarian) design (D) educational programme, focusing on the development of thinking skills of students. Progressive pedagogical schools, focusing on the skill-development of students through active learning, have long recognized the ability of art education to contribute to personal development and the positive influence of art education on the learning process. On the basis of this knowledge, the relationship between the science and arts, implemented in constructive activities is an important element of the programme. It creates a possibility for effective learning on the basis of arts, as well as design thinking, and planning. The target of the programme is to develop, test and implement a new, design-based method. The intended outcome of the development process is a curriculum that contains a detailed educational programme, learning support material and teacher training for both elementary and secondary schools. Designers, educational experts and teachers work together not only in the programme development, but in the process of testing and implementation too. Design thinking, which is based on the solutions of real problems, needs not only cooperation and complex thinking, but inquiry based learning as well. While the most important task of the method is the development of creativity and problem-solving thinking, interdisciplinarity is also a core element of the conception. So art teachers or teachers with visual art degree have to cooperate and work in pairs with other teachers (typically trained for mathematics, natural sciences, or informatics). This is a great challenge for teachers because of the traditions of teaching. Actually the teacher trainings and tests of the learning materials are realized in several school, existing in 33 convergence regions of the country.



↑ **Picture 4:** *Design Thinking in teachers' development course*

Initiatives by market agents and NGOs

A multinational energy company, E.ON initiated 'EnergiaKaland' (EnergyAdventure) programme. It is a complex energy education, to improve the teaching about energy related issues. It offers a wide range of support tools: free on-line platform with teaching games, support materials and in-service trainings for teachers, a volunteer network and art grants for schools.

‘EnergiaKaland’[7] is a Corporate Social Responsibility (CSR) programme to support energy education. It is run by the Hungarian group of the international private energy company, E.ON. The Hungarian programme is an adapted and extended version of the EnergyExperience[8] programme of British E.ON group. The programme was adapted to the Hungarian context in co-operation with the Ministry of Education ten years ago, and has been supported by educational experts from higher education and research institutions.

The main objective of the programme is to provide students with varied learning activities on the issues of energy. Opportunities includes: evaluating and analysing data, tests, experiments on local energy consumption and many more. Beside this, the programme could also improve the parents’ and customers’ knowledge and understanding of energy issues. Involvement in energy issues helps to change consumer attitudes and behaviour. The programme could be used in many ways: independent, paired or small group work in classrooms, classroom and field observations, text and data processing, problem and task solving, games, measurement and experimentation, pedagogical projects, frontal discussion. With the support of ‘EnergiaKaland’, students not only get acquainted with most important data and facts about energy, but they make virtual decisions on the generation, distribution and use of energy, and they get to know the impact of their decisions. Energy adventure offers a number of opportunities for students to become actively acquainted with the energy aspects of their own environment and to contribute to their energy-conscious transformation.

The Programme is not a mere science programme, but it is connected to that. It tries to present the complex role that energy plays in our society and to build bridges between schools and energy companies, and between science and arts. ‘Energy is valuable, energy is interesting’- is the motto of the programme. Students, participating in this programme, prove that energy can be a theme that motivates students to learn about science and can support them to prepare for a socially active and responsible but also an enjoyable life at the same time.

The structure of the programme

The centre of ‘EnergiaKaland’ programme is its website, containing multimedia learning materials for students aged 5-18 and their teachers. The ‘Teacher Room’ part of the website offers auxiliary materials with printable off-line activity cards, and concrete activity plans for teachers. The programme is run on a traditional standard school terminal with medium bandwidth internet access and software requirements are free. That way it is accessible to anyone.

The learning content consists of five chapters that are based on one another (but can be used independently too), describing the widening environment around growing children:

- *EnergiaKuckó (EnergySnug) for 5-7 year olds*
- *EnergiaOtthon (EnergyHome) for 6-10 year olds*
- *EnergiaVáros (EnergyCity) for 9-12 year olds*
- *EnergiaOrszág (EnergyCountry) for 11-15 year olds*
- *EnergiaVilág (EnergyWorld) for 14-18 year olds*

[7] http://www.energiakaland.hu/

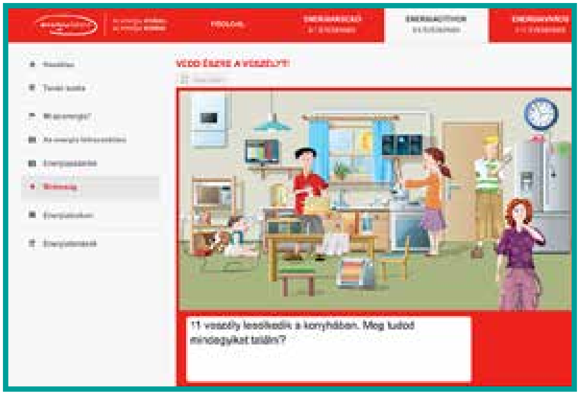
[8] https://www.bitc.org.uk/resources-training/case-studies/eon-eon-energy-experience

Each module contains a set of learning games, which younger children can use with the help of their parents or teachers, and older children can use alone or in groups. All game has a written introduction, not just about how to use the game but also some hints about how children can obtain the best results. Beside this, an energy lexicon with the explanation of the main concepts about energy and a collection of animated pictures explaining the different ways to generate energy is available in all modules. All of these online materials can be used in classrooms as tools for teaching. They can be a part of a lesson, a tool for differentiation, or a whole lesson can be based on them using the activity descriptions available in the “Teacher room” part of the website. There is a school which planned a whole month long Energy project and ran it entirely based on the ‘EnergiaKaland’ activities.

Students have to make decision about the possible energy sources for different countries based on the data provided.

↑ **Picture 5:** *Example from the EnergyWorld part of the portal*

Students have to find all the possible dangers on the picture. There are eleven. Could you find all of them?



↑ **Picture 6:** *Example from the EnergyHome part of the portal*

In addition to the website, E.ON has established a nationwide network of E.ON employees who give free energy lessons to schools on a voluntary basis E.ON staff volunteers. Volunteers are trained each year to get acquainted with the latest developments in ‘EnergiaKaland’ and the latest news from the world of energy. Every year E.ON organizes different competitions for students and their teachers in energy related topics. Among these competitions there were drawing competitions for young children, video competitions for older student, competitions for writing energy-tales for teachers and teacher students.

Since its debut ‘EnergiaKaland’ has found its way into the educational system and into the life of E.ON Company. Now more than a thousand schools and kindergartens use some elements of the programme; receive E.ON volunteers or participate in the competitions programme. This could be considered as a quality feedback of the programme. On the other hand, the programme is growing also within E.ON. There were an average 20-25 people at the yearly training for new volunteers, but at the last training there were 44 participants. In addition, E.ON has started to develop a new module of the programme for vocational schools focusing on safety issues.

These developments are clear signs that 'EnergiaKaland' could be a tool for effective energy education and in the future it could serve as a basis for not just general education for energy issues but also to help to orient students to energy related professions and assist their successful and enjoyable professional learning too.

Universities and market agents from the information science field have been supporting the *LEGO Education Project*[9]. It contains four different educational tool packages and teacher trainings related to them. These are the following: (1) More to Math (mathematics for the grades 1 and 2.), (2) Story Starter (digital story telling), (3) WeDo2.0 and (4) Mindstorms EV3 (robot programming for teaching natural sciences). 50 public schools in Hungary participate in the programme of 'LegoMatek' (MoreToMath) and 'Robot programming' (WeDo 2.0 and Mindstorms).

The aim of the LEGO Foundation is to ensure that the fundamental value of play is understood, embraced and acted upon and to build a future where learning through play empowers children to become creative and engaged lifelong learners in many countries. The Foundation works in partnership with non-profit organisations, social enterprises, academic institutions and governments from around the world to transform attitudes and behaviours to learning through play. To achieve this aim, the products of Lego Education are offered for use in schools. The majority (80%) of these products are connected to the education of STEM.

The results of the Hungarian practice of the 'LEGO Matek' show that even for the youngest students, teachers can use the programme successfully in personalised learning. (In Hungary there are two separate target groups of children: (1) those who need extra support to close up to the average, and (2) the group of talented children.) For the children in the first target group the manual activities and the pictures contributed to construct a stable knowledge in the four arithmetical operations. In the group of talented children, teachers could successfully use the programme for differentiation.

A great advantage of the programme is that it is easy to use in the ordinary math lessons.

A part of those 20 schools which have been participating in the 'Robot programming', used the programme in the framework of traditional lessons, but the other part of these schools offered it as an extracurricular activity for the children. Experiences show that the game has a positive effect on the motivation for learning, especially in the disabled group of children. The methodology, offered by different packages of the Lego programme can be used in different subjects and it can contribute to the improvement of complex thinking about the nature. After the first positive experiences an agreement for cooperation was signed by the Hungarian government and Lego in 2016. This agreement gave a possibility for the Hungarian schools to participate in the game-based education. Educational government supports this process by an application system, subsidized by European funds. Schools, with the results under the average or/and existing in disadvantaged regions of the country, have priorities in the process of the evaluation of the applications. An additional target of the cooperation is to encourage teachers to use game-based teaching. During the training programmes teachers are trained to use these educational tool packages therefore they can contribute to the radical change of the teachers' thinking about the process of teaching and learning. These teacher trainings have been realized in cooperation of the Lego and the Hungarian teacher training institutions. They work together on the adaptation of the tool packages to the Hungarian education system as well.

[9] *http://folyoiratok.ofi.hu/uj-kozneveles/tanitas-es-robotprogramozas-lego-val*

The Digital School Pilot Programme started with the guidance of the ICT Association of Hungary (IVSZ). The running of the programme has been realized in cooperation of the state, NGOs and market agents (such as Microsoft, Samsung, T-Systems, Telenor and Vodafone). It aims at improving the digital competence of students by developing and testing digital curricula and learning support materials for public schools.

Lessons and suggestions

The success of STEAM education has crucial importance in sustaining the 21st century economy. Improving the 21st century competencies, as well as mathematical competence and basic competencies in science and technology, and the cultural awareness and expression of students is a strategic goal of the education government, although there is not a special STE(A)M-development strategy in Hungary. Different powers are supportive in achieving this strategic goal, but several effects hamper the process.

Several isolated programmes have been running in the Hungarian schools under the umbrella of STEAM education and most of them are embedded in the international context. They are subsidized by the EU sources, or by multi-national companies. While these programmes are running as punctual project, embedding them into the education system is always a crucial element. A wider integration should be carried out on the basis of a systematic analysis of the results of the isolated experiences.

It is a new trend, that profit oriented companies take an active role in the stage of education, with the aim of supporting the successful education of the next generation. This phenomenon has advantages and disadvantages as well. It is important, that it takes new resources into the education system and supports the flexibility of the education activities. They can refresh the traditional education by offering joyful and exciting programmes and possibilities for the schools and for the students. They can contribute to the developing of the ICT competencies, while most of them use different ICT tools. They could make the education stage more colourful, but in the majority of cases teachers do not use them systematically in the learning process. Teachers should support using these possibilities. Teachers, methodological experts and professional programme developers with the experts of the companies should work together to avoid the danger of a non-professional programme development.

The lack of Science teachers is a serious problem in the system. Those teachers, who have not participated in the different pilot programmes of STEAM education, can create a very traditional content and methodology in teaching and learning these subjects.

It is clear, that the government itself is not able to handle the problem. Cooperation with the profit-oriented companies, with the NGOs, universities, and R&D Institutions could create a wide network, which could support teachers to fulfil the targets.

Beside the content regulation, and the Strategy for developing the public education, an action plan and a supporting environment should help to achieve the targets. Renewing the teacher training, the Continuous Professional Development of teachers and running schools as learning organisations are core elements of the successful change.

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Picture 1 / JR-Maglev MLX01:

https://www.google.hu/search?q=-jap%C3%A1n+vas%C3%BAt&rlz=1C1CHWA_huHU-614HU615&source=lnms&tbm=isch&sa=X&ved=0a-hUKEwi4z4WQzeHZAhVkJpoKHbPjB-cQ_AUICig-B&biw=1094&bih=462#imgrc=l0Kp32OTG7lHtM

Picture 1 / Rocket:

https://www.google.hu/search?rlz=1C1CH-WA_huHU614HU615&biw=1094&bih=462&t-bm=isch&sa=1&ei=_LyjWoyxKIHw6ATrs-JrIDg&q=rocket%2C+steam+engine&oq=rock-et%2C+steam+engine&gs_l=psy-ab.3..0i1 9k1.6991.10441.0.11159.14.14.0.0.0.0.132.999. 13j1.14.0....0...1c.1.64.psy-ab..0.14.998...0j0i67k-1j0i30k1j0i13k1j0i13i30k1j0i8i30i19k1j0i30i19k1.0.Rr-RoR-Hxoro#imgrc=DJhT650ePTP-XM

Picture 2 / Left side classroom:

http://www.jgypk.hu/mentorhalo/tananyag/noneve-les/105_a_nk_iskolztatsa_s_trsadalmi_karrierlehets-gei_magyarorszgon_a_szzad_els_felben.html

BOSNIA & HERZEGOVINA

Authors

Maja Stojkić

Education:
Master specialist of diplomacy and diplomatic communication

Teacher of Croatian language and literature and English language and literature

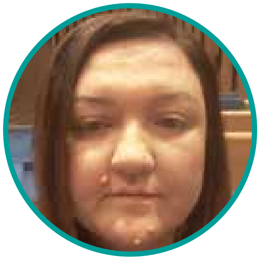
Fields of expertise / experience:
Eighteen years of work experience in education (nine of which in teaching). Experienced in organizing, HRM, project developing, financial planning and reporting. Successfully completed a number of specialized courses on education and governance. Working as a Director of the Agency for Pre-primary, Primary and Secondary Education in BiH.

Marija Naletilić

Marija Naletilić, PhD is head of the Common Core Curricula (CCC) Department with the Agency for Pre-primary, Primary and Secondary Education and leads the project on developing the CCC based on learning outcomes and guidelines for implementing CCC in schools. She has authored a number of scientific and professional papers on the history of Bosnia and Herzegovina in the 19th and 20th centuries and delivered workshops on innovative approaches to history teaching. She has collaborated with the Georg Eckert Institute in Germany and participated in international scientific seminars held in numerous countries.

She has chaired the Committee for the Reform of History Teaching in BiH and reviewed history textbooks for primary education and gymnasiums. She has participated in the drafting of the Action Plan for the Development and Implementation of the Qualification Framework in BiH and in the development of the Manual for the Development of Methodologies for Quality Assurance of General Education Qualifications within the Qualifications Framework in BiH.

Authors



Danica Vasilj

Danica Vasilj is an adviser for classroom teaching with the Common Core Curricula (CCC) Department in the Agency for Pre-primary, Primary and Secondary Education. She is a member of the team currently working on the development of the new Common Core Curricula in Bosnia and Herzegovina. She is skilled in art therapy, professional orientation, BiH Skills Passport, entrepreneurship and entrepreneurial competencies in education, and in quality management. She has experience in committees such as the Committee for the Reform of History Teaching in BiH and in quality education in multiethnic societies. She has also participated in the preparation of various manuals in the field of education.

Abstract

The process of defining learning outcomes was a crucial part of the improvement of the education system in Bosnia and Herzegovina in order to obtain better student achievements using improved methods of teaching and learning.

Common Core Curricula (CCC) based on learning outcomes also created conditions for the implementation of STEM education, using an interdisciplinary approach to coordinate the teaching of different subjects and their integration in everyday life.

Developing the Commom Core Curricula based on learning outcomes, using a competence-based approach, the Agency for Pre-Primary, Primary and Secondary Education initiated the education reform in Bosnia and Herzegovina.

Nevertheless, full implementation of the education reform in Bosnia and Herzegovina requires urgent steps in order to achieve better quality of the policies and processes, having in mind neccessity of implementation of the Common Core Curricula, as well as the continuous professional development of all participants in the educational processes.

Developing Common Core Curriculum based on learning outcomes in Bosnia and Herzegovina – process, implementation, challenges

Introduction

Bosnia and Herzegovina has been an independent and sovereign state since 1992, following a referendum for separation from Yugoslavia. In education, competencies were transferred to the level of the entity Republika Srpska, ten cantons in the Federation of BiH, and the Brčko District of BiH, which are competent under the law to implement education policies in accordance with the effective laws in Bosnia and Herzegovina.

First substantial changes in the education sector were implemented with the signing of the Agreement on the Common Core Curricula in 2003.[1] The Agreement, signed by all competent ministers of education of the entities and cantons, and of the Department of Education of the Brčko District of BiH, enabled adoption of education framework legislation that, with certain reforms, remain in force. It imposed the obligation to organise instruction based on the curricula, including the Common Core Curricula as of the academic year 2003/2004, while the eight-year primary education system was still in effect.

The concept of the Common Core Curricula was based on the list of school subjects and the accompanying programmes for primary school and grammar schools, and it corresponds with the traditional content-based and teacher-based curriculum. In fact, the Common Core Curricula provided the bases for development of all 12 curriculas in BiH with as much common content for designing curricula as possible, and thus, ensures the mobility of pupils across Bosnia and Herzegovina.

However, such Common Core Curricula did not meet the needs arising from the reforms and progressive introduction of the nine-year primary education system between 2004 and 2009.

Simultaneously to these reforms, in late 2008, the Agency for Pre-Primary, Primary and Secondary Education, a state-level institution in charge of developing the Common Core Curricula, establishing standards and validating results achieved in education, became operational.[2]

[1] *Agreement on the Common Core Curricula, Sarajevo, 2003.*

[2] *Law on Agency for Pre-school, Primary and Secondary Education, Sarajevo, 2007.*

One of its first tasks, defined by the Agency's Strategic Plan[3], was to analyse the effective curricula in Bosnia and Herzegovina, countries in the region and beyond, in line with international educational standards that ensure coherency, compatibility and mobility. The analysis revealed the need to improve the existing common core curricula by shifting the focus on student learning outcomes. At the same time, state-level strategies in education were adopted. They provided the main directions of development of education in Bosnia and Herzegovina until 2015, and clearly defined the Agency's role[4]. The Strategy is based on the global approach to education, defined in the UN Millennium Declaration and the European Union's goals with respect to enhancing the quality and effectiveness of education and training, its accessibility and mobility inside the common European area.

Learning outcomes-based common core curricula

Defining learning outcomes is a crucial part of the improvement of the entire education system in Bosnia and Herzegovina, with the ultimate goal being better student achievements through the improvement of teaching and learning. Specific and measurable student learning outcomes should describe students' knowledge and capacities. They focus on application and integration of knowledge and skills relevant for students' life and work in the 21st century. They describe WHAT to teach, not HOW to teach and learn. They do not list curriculum content and they do not prescribe what teachers need to do in class, rather, they are focused on students and their activities.

Development of the learning outcomes-based Common Core Curricula began in accordance with the Strategic Plan of the Agency for Pre-school, Primary and Secondary Education, 2012-2016. Plan of activities and the learning outcomes development roadmap, shown on the right, were made.

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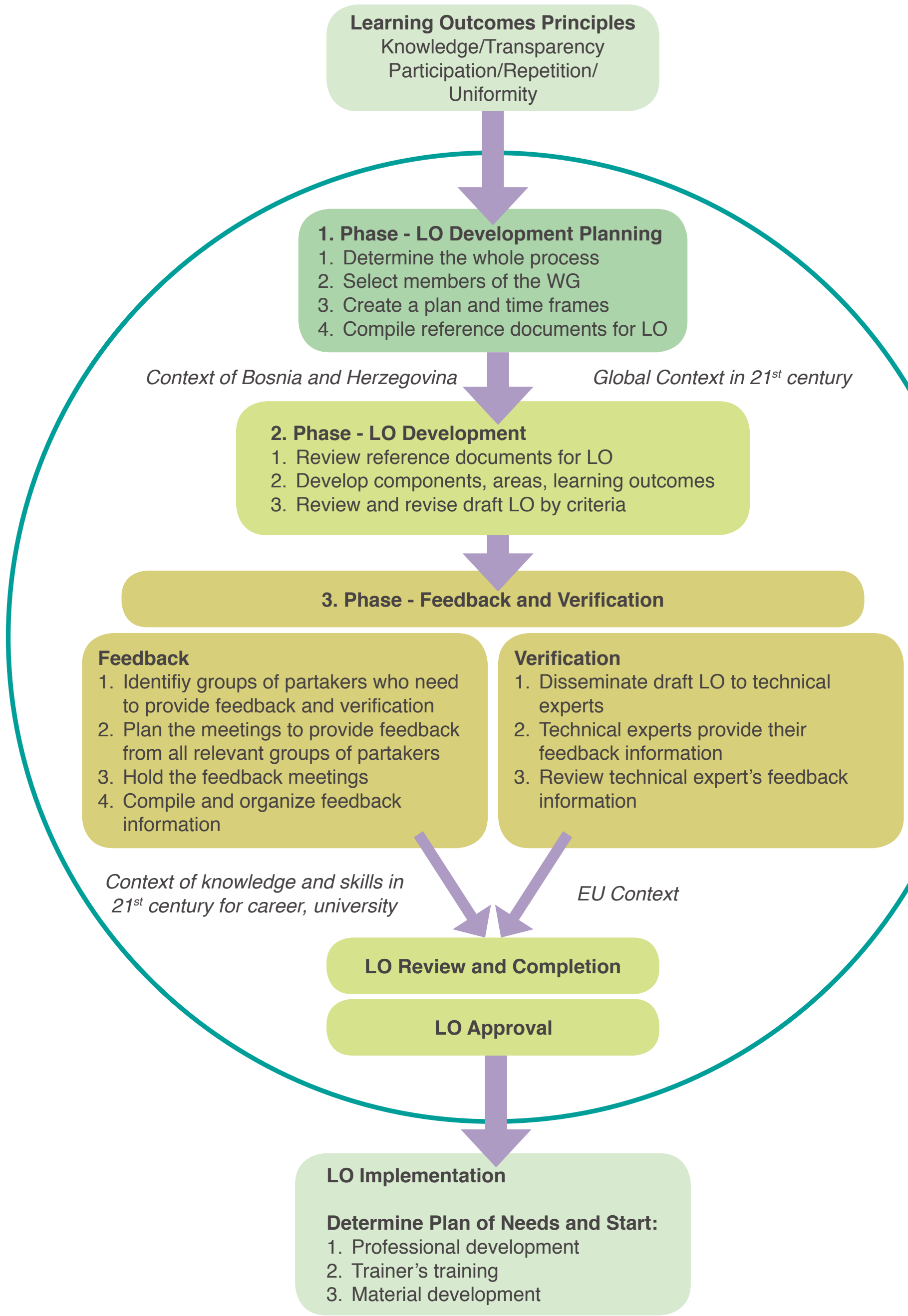
[3] *Strategic Plan of the Agency for Pre-school, Primary and Secondary Education 2012-2016, Mostar, 2011.*

[4] *Strategic Directions of the Development of Education in Bosnia and Herzegovina, with implementation plan, 2008-2015, Sarajevo, 2008.*



↑ ***Figure 1:*** *Learning outcomes development roadmap*

As the development of learning outcomes requires the inclusion of key competencies, the European framework on key competencies and the situation in Bosnia and Herzegovina were studied. The analysis and the feedback from teachers and students established that, in addition to eight key European competencies, the physical-health and creative-productive competencies needed to be developed. Thus, the following ten key competencies were ultimately defined for Bosnia and Herzegovina:

1. *Communication in the mother tongue*
2. *Communication in a foreign language*
3. *Mathematical competencies and basic competencies in science and technology*
4. *IT competency (informational, media, technological)*
5. *Learning to learn*
6. *Social and civic competency*
7. *Sense of initiative and entrepreneurship*
8. *Cultural awareness and expression*
9. *Creative-productive competence*
10. *Physical – health competence*[5]

Based on the European framework on key competencies, ten key competencies for Bosnia and Herzegovina, an analysis of the effective curricula in Bosnia and Herzegovina, and the analysis of curricula of the countries in the region, the Agency defined the following eight education strands with subjects within the strands:

1. ***Communication** (Common Core Curricula for the mother tongue and the Common Core Curricula for foreign languages)*
2. ***Mathematics***
3. ***Natural sciences** (Common Core Curricula for physics, Common Core Curricula for chemistry, Common Core Curricula for biology, and the Common Core Curricula for geography)*
4. ***Social science and humanities** (Common Core Curricula for history and the Common Core Curricula for civic education)*
5. ***Technology and information technologies** (Common Core Curricula for information science and the Common Core Curricula for technical culture)*
6. ***Art** (Common Core Curricula for visual arts and the Common Core Curricula for music culture/art)*
7. ***Physical training and health***
8. ***Cross-curricular and cross-subject strand** (anti-corruption, career orientation and entrepreneurship)*[6]

[5] *Key competencies and life skills in Bosnia and Herzegovina, Sarajevo, 2013*

[6] *Learning outcomes-based Common Core Curricula for Bosnian, Croatian and Serbian, Mostar, 2013, p. 6*

A single methodology was identified and applied to all education strands and subjects within the strands. Its aim was to define strands, components, student learning outcomes, and their relevant indicators. A strand is an organised, coherent set of knowledge, skills and attitudes within a certain field or school subject. Components are smaller units within strands that represent and additionally define certain knowledge and contents. Learning outcomes are statements about what a student should know, understand, and be capable of doing and demonstrating after completing a certain learning process, and are used to define components. Indicators define the degree of achievement relating to the set outcomes in accordance with the student's age and are defined for the end of pre-school education (age 5-6), 3rd grade (age 8-9), 6th grade (age 11-12), nine-year primary education (age 14-15), and secondary school education (age 18-19)[7].

The Revised Bloom's taxonomy of education goals, described by active verbs in the present tense, was used when defining the learning outcomes and indicators[8].

It is important to note that key competencies that need to be developed were determined through the defined indicators for wall strands. In order to simplify the application, key competencies were in all documents marked with different colours and briefly explained, as shown in the following figure.

[7] *Guidelines for implementation of learning outcomes-based Common Core Curricula, Mostar, 2015.*

[8] *Krathwohl et al. (2001). A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives, Longman.*

↓ ***Figure 2:*** *Key STEM related competencies in Bosnia and Herzegovina with a colour code and explanation*

Key competence	Crosscutting indicators (indicators)
Mathematical competence	• Has ability and readiness to use mathematical thinking (logical and spatial thinking) and presentation (of formulas, models, constructions, charts/diagrams) that apply universally when explaining and describing reality. • Has knowledge of mathematical notions and concepts, including the most important theorems in geometry and algebra. • Respects the truth as the basis of mathematical thinking.
Science and technology competence	• Has ability to understand and apply (decoding, interpretation and differentiation) various types of presenting mathematical elements, phenomena and situations, selection and switch of the presentation style if and when necessary • Has ability and readiness to use the knowledge and methodology to explain nature. • Has competence in technology as interpreted as the application of knowledge in order to change the natural surroundings to fit the human needs. • Understands the relationship between technology and other areas: scientific progress (e.g. in medicine), society (values, moral issues), culture (e.g. multimedia), or environment (pollution, sustainable development). • Has readiness to acquire knowledge in natural sciences and interest in science and scientific and technological careers.
IT competence (informational, media, technological)	• Uses critical thinking in the field of information-communication technology for obtaining, validating, and storing information, for production, presentation and exchange of information and for participation in virtual social networks; • Has awareness of the differences between the real and virtual world; • Uses technology to develop creativity, innovation and inclusion in society, uses technology to support critical thinking; • Respects privacy when using social networks, respects ethical principles, recognizes the reliability and validity of information obtained, uses networks to expand horizons.

Learning to learn	• Develops co-responsibility for own learning, self-assessment and defining of own learning goals: – *developing awareness of own abilities and strong and weak points, learning styles, types of intelligence, as well as the ability to identify own needs in order to apply own strategies and procedures in the learning process.* • Develops the ability to correct and improve oneself (self-regulation): – *pre-planning, execution, control, correction of various types of communication activity (reception, interaction, production, mediation).* • Has ability to use various learning methods and strategies: – *knowledge and conscious use of various learning strategies;* – *enabling a student to gain the ability to discover his/her most successful and fastest learning method, to choose different options and apply the best ones in practice;* – *developing critical view of the subject matter of learning in school and of own learning process;* – *ability to organise and arrange own learning, developing persistence;* – *developing self-motivation, self-confidence, need for continuous learning.*
Creative-productive competence	• Develops complex opinion: – *summarising, generalising, using higher cognitive abilities such as analysis, synthesis, validation, use of critical opinion (differentiating between facts and opinions, supporting theories with arguments);* – *use of logical structuring and listing of arguments* • Develops creativity and the need for expression, as well as the sense of aesthetic value: – *production and connecting of various ideas, production of assumptions and various products;* • Develops openness for different cultural expressions and preparedness for developing own creativity and ability to express oneself: – *ability to tolerate opposing ideas;* – *making conclusions independently;* – *developing positive attitude and readiness to relativize own position and value system, developing readiness for divergence from common treatment of other cultures.* • Supports curiosity, wish for new knowledge: – *enabling expression of own thoughts, ideas, emotions;* – *developing ability to observe, participate and integrate new experiences and readiness to change the previous ones.*

Sense of initiative and entrepreneurship	• Manages projects • Recognises his/her own strong and weak points • Is cooperative and flexible in team work • Has constructive cooperation in activities and use of group work skills • Understands risk management and uses it for development of awareness of responsibility.

Please note that every defined strand includes a different number of key competencies, depending on the specificity of a particular strand.

Drafting the learning outcomes-based Common Core Curricula also created conditions for implementing the approach in STEM education, that is based on the interdisciplinarity and the proximity to situations and problems in everyday life. The main idea of this approach to STEM education is coordination of the teaching different subjects and, if it is possible, integration over links to practical applications.

In fact, the practice so far and the TIMSS research conducted in 2007 pointed to the shortcomings of the education systems in BiH, and the need to introduce the STEM approach in teaching was identified by shifting the focus to learning outcomes and interdisciplinary, which is the basis for change in the approach to teaching and training for a knowledge-based economy.

STEM in Bosnia and Herzegovina includes the following subjects:

- *physics*
- *chemistry*
- *biology*
- *geography*
- *mathematics*
- *technical culture*
- *information science*

The above-mentioned subjects are integral parts of natural sciences, mathematics, technology and information technologies.

Since we analysed the effective curricula in the neighbouring countries, the EU and beyond when defining learning outcomes for all the strands, while drafting the Common Core Curricula for STEM subjects, we noticed that some countries, for example, the USA, have the subject called “engineering” as part of the STEM group.

There is no such subject in Bosnia and Herzegovina, and it was thus necessary to make adjustments in accordance with our conditions and needs[9].

Important contributions to the approach to STEM education was made by Save the Children International, which drew up operational curricula for all STEM subjects in BiH based on learning outcomes-based Common Core Curricula. The operational curriculum includes the cross-curricular component and connection among subjects in the future curricula, as well as the annual and monthly syllabus. It is exactly the development of key competencies and skills through STEM teaching that will result in better student achievements, and ultimately lead to the enhancement of knowledge-based economy sectors. The STEM curriculum will enable a large number of links among subjects and a different approach to teaching and learning and will be the means that teachers will use to create and implement activities in the classroom.

The connection between subjects and their respective connections to real life also leads to increased motivation of students to adopt the material. Teaching learning outcomes-based STEM curricula results in more intensive networking and cooperation between teachers in the preparation and implementation of activities as well as in a clearer and more comprehensive picture of the knowledge students acquire from various aspects, applicable in real life

[9] *Manual for training teachers to apply Operational curriculum for STEM competencies, Save the Children International, office in Bosnia and Herzegovina, Sarajevo, 2018.*

[10] *Manual for training teachers to apply Operational curriculum for STEM competencies, Save the Children International, office in Bosnia and Herzegovina, Sarajevo, 2018.*

Based on the analysis, and keeping in mind the current development and potential of Bosnia and Herzegovina, ten key sectors were defined:

1. *information and communication technologies*
2. *entrepreneurship*
3. *business and finance*
4. *energy generation, transmission, efficiency*
5. *modern agricultural production*
6. *sports*
7. *technology of materials and high technology production*
8. *tourism*
9. *arts, entertainment, and media*
10. *healthcare and medicine*

In order to ensure further implementation, it was necessary to create a means for identification of targeted behaviours, that is, processes that help teachers in linking the current content and the content focused on the learning outcomes and indicators.

Targeted behaviour represents a description of the most important skills and concepts that students need to learn at the level of one grade, that is, it represents what students must know and be able to do.

As for assessment, students were observed to make an effort if they know they will be assessed. Therefore, assessment structure and content play a key role in the success of STEM integration at school. Factual knowledge and ability to participate in solving problems contribute to better understanding, memorising, and applying the knowledge acquired.

That is why it is important to develop a broad spectrum of assessment tools needed for better evaluation of students' achievements. It is particularly important to provide students with feedback on the level of their achievement, so that they would have the opportunity to completely develop their full potential because the approach to STEM education encourages students to participate in team work through various projects, interpersonal communication, organisation of work, as well as other soft-skills relevant for living and working in the 21st century.

In order for the process of defining student learning outcomes to be clearer illustrated, you will find an example of indicators for specific subjects and age, with included competencies mixing through the defined indicators on the next page.
→

↓ ***Figure 3:*** *Indicators for the end of pre-school education from the learning outcomes-based Common Core Curricula for my surroundings, nature and society, nature and biology*[11]

Strand 4: Human Biological And Social Being				
Component 3: Healthy life habits and functioning of a human in accordance with natural and social laws				
Learning outcomes: 1. accepts views that contribute to own health 2. accepts views that contribute to sexuality and relations between genders.				
Indicators, according to the student's age, for:				
end of pre-school education	end of 3rd grade (age 8-9)	end of 6th grade (age 11-12)	end of nine-year primary education (age 14-15)	end of secondary school education (age 18-19)
1.a shows health-related and hygiene habits and habits related to healthy eating towards preserving human health **1.b** recognises proper diet, activities and rest at free time	**1.a** explains the importance of maintaining personal hygiene and health of specific organs **1.b** accepts proper eating habits, activities and rest at free time	**1.a** judges the importance a healthy diet has on maintaining a healthy lifestyle	**1.a** explains the importance of physical activity for human health **1.b** explains the importance of a balanced diet for a healthy lifestyle **1.c** identifies mutagens detrimental to man **1.d** names adverse consequences caused by mutagen factors	**1.a** establishes how important hygiene and healthy diet are for preserving human health **1.b** Judges the impact of pesticides, heavy metals, radioactive substances, antibiotics, genetically modified compounds and additives on human life **1.c** proposes measures to protect the environment from adverse consequences caused by mutagen factors
			2.a presents views of responsible sexual behaviour and protection that reduces the risk of STDs	**2.a** explains different views of sexuality, contraception and STDs as prevention measures in a healthy lifestyle.

[11] *Learning outcomes-based Common Core Curricula for my surroundings, nature and society, nature and biology, Mostar, 2017.*

↓ ***Figure 4:*** *Indicators for the end of 3rd grade of the nine-year primary education for the learning outcomes-based Common Core Curricula for mathematics*[12]

Strand 1: Sets, numbers and operations

Component 1: Sets, numbers and numerical systems

1. Analyses features and relations among sets in different forms of presentation and applies them when solving problems in mathematics.
2. Analyses features and relations among numbers and numerical systems, and uses symbols and various presentations.

Indicators, according to the student's age, for:

end of pre-school education (age 5-6)	end of 3rd grade (age 8-9)	end of 6th grade (age 11-12)	end of nine-year primary education (age 14-15)	end of secondary school education (age 18-19)
1.a recognises and names elements of a set, presents a set with a model and a drawing. **1.b** distributes elements of a set and singles out subsets within a set. **1c.** forms a set with a given number of elements, counts and states the number of set elements.	**1.a associates elements of sets, presents sets on a drawing.** **1.b compares sets by the number of elements, recognises common characteristics and associates, relocates and supplements a set.**	**1.a** notes down sets in equivalent notes and presents them on a drawing (Euler-Venne diagram) using symbols. **1.b** forms a subset, union, intersection and difference of sets, presents them on a drawing and with symbols **1.c** forms an ordered pair and a direct product of two sets, presents them on a drawing and with symbols	**1.a** presents solutions of equations, inequalities, domains, codomains, graphs of function using sets. **1.b** compares sets by their similarities and differences on specific sets (draws an illustration). **1.c** recognises injective and surjective refiguring. **1.d** forms an ordered pair whose components meet specific relations (systems of equations).	**1.a** discusses potential solutions of equations, inequations, domains, codomains, graphs of function, using sets and operations with sets. **1.b** interprets and analyses the concept of a universal set and complement. **1.c** analyses injective and surjective refiguring, cardinal number of a set. **1.d** uses basic elements of Boolean algebra and writes down random sentences using symbols. **1.e** uses a set of ordered pairs, multiple n, and connects them with analytical geometry on a plane and in space and solutions of systems of equations and inequations.

[12] *Learning outcomes-based Common Core Curricula for mathematics, Mostar, 2015.*

end of pre-school education (age 5-6)	end of 3rd grade (age 8-9)	end of 6th grade (age 11-12)	end of nine-year primary education (age 14-15)	end of secondary school education (age 18-19)
	1.c Puts in correlation natural and social phenomena using sets and set relations.	**1.c** Uses sets and operations with sets in examples from daily life and illustrates them on a drawing.	**1.c** Uses a set and correlations in a set in solving informatics and technical problems.	**1.f** Connects correlations in a set with social and natural phenomena, interprets them, draws conclusions based on mathematical expression.
2a. recognises signs for numbers. **2b.** recognises a number sequence and states ordinal numbers (knows who/what is the first, and who/what is the last) **2c.** provides names for numbers in everyday situations. **2d.** compares quantity of specific items in sets (“less“, “more“, “equal“, “more by one“, “less by one“).	**2a. reads and writes down numbers up to 100.** **2b. presents and compares numbers up to 100 on the numerical semi-straight line.** **2c. uses ordinal numbers up to 100 and signs for Roman numbers up to 20.** **2d. differentiates between even and odd numbers and notices numerical patterns, e.g. predecessor and successor.** **2e. differentiates between a number and a figure and words for numbers, and uses them in communication.** **2f. uses letter as a sign for a number.**	**2a.** reads and writes down integer numbers, positive fractions and decimal numbers. **2b.** compares integer number up to 1,000,000, positive fractions and decimal numbers shown differently using mathematical symbols and the number line. **2c.** knows the features of N, Q+ sets of numbers and their mutual relation. **2d**. explains place value of decimal numbers. **2e.** uses Roman numbers up to 1000. **2f.** differentiates between real and irrational fractions and mixed numbers. **2g.** uses general numbers and variables (variable, unknown), fractions presented with application in practice.	**2a.** differentiates presentations of real numbers (rational and irrational numbers according to their decimal record). **2b.** compares real numbers and presents them on the number axes. **2c.** analyses the characteristics of N, Z, Q, I, and R sets of numbers and their mutual relations. **2d.** connects percentages with fractions and applies them in problem situations.	**2a.** analyses the connection and mutual relation between real and complex numbers using various presentations. **2b.** presents complex numbers analytically and in geometry in a complex plane and in trigonometric form. **2c.** applies connections among the N, Z, Q, I, R, C sets of numbers. **2d.** analyses the binary and decadic recording.

↓ ***Figure 5:*** *Indicators for the end of 6th grade of the nine-year primary education from the learning outcomes-based Common Core Curricula for my surroundings, nature and society, society and geography*[13]

Strand 1: Earth in space as a living environment				
Component 3: Presentation of Earth's surface				
Learning outcomes: 1. uses different methods of finding one's way and orientation on Earth, in the living space 2. uses various instruments to find out time and orient in space 3. interprets geographic elements and content on a map and globe				
Indicators, according to the student's age, for:				
end of pre-school education	end of 3rd grade (age 8-9)	end of 6th grade (age 11-12)	end of nine-year primary education (age 14-15)	end of secondary school education (age 18-19)
1.a orients oneself in familiar space	**1.a** determines the cardinal and intermediate directions and finds orientation with the help of markings in the nature	**1.a differentiates and explains orientation using celestial bodies, structures, items, and instruments**	**1.a** applies different methods of orientation on the Earth's surface (map, compass, GPS)	**1.a** combines application of various instruments for orientation on the Earth's surface
2.a recognises specific parts of the day and week intended for specific activities	**2.a** names and explains units of time (minute, hour, day, week, month, year)	**2.a uses instruments and a map for orientation in space**	**2.a** makes and analyses graphs resulting from use of measuring instruments	**2.a** Uses geographic information system (GIS), 3D relief modelling, and the global positioning system (GPS) **2.b** analyses and compares cartographic projections
3.a notices that the Earth is round while looking at a globe	**3.a** Recognises the Earth's shape while looking at a globe **3.b** recognises basic colour (blue, brown and white) and what they mark on a globe and maps	**3.a determines directions, learns geography terminology, uses maps, globe and the school atlas.**	**3.a** analyses natural geographic and socio-geographic features using a map	**3.a** independently makes thematic maps on blank maps

[13] *Learning outcomes-based Common Core Curriculum for my surroundings, nature and society, society and geography, Mostar, 2017.*

↓ ***Figure 6:*** *Indicators for the end of the nine-year primary education from the learning outcomes-based Common Core Curricula for physics*[14]

Strand 4: Oscillation, waves and modern physics	
Component 4: Astronomy and Astrophysics	
Learning outcomes: 1. describes composition and structure of space 2. describes the model of creation and evolution of space and interprets forming and development of stars	
Indicators, according to the student's age, for:	
end of nine-year primary education (age 14-15)	end of secondary school education (age 18-19)
1.a uses information technology to collect data on the historic development of ideas about space, describes the Sun's position in the Milky Way galaxy, and describes planets and the size of the Solar system	**1.a** describes, based on observation and/or simulation, main objects in space (e.g. stars, constellations, galaxies and groups of galaxies)
1.b interprets phenomena caused by movement of Earth and Moon (e.g. change of day and night, of seasons, and ebb and tide)	**1.b** interprets meanings of an astronomical unit
2.a states that space has finite age and that, according to the latest estimates, it is 13.8 billion years	**2.a** describes the Big Bang theory as "space-time", and interprets Hubble's Law and cooling of space
	2.b researches and describes the life cycle of stars and the concept of dark matter using various sources of knowledge, including information technologies

[14] *Learning outcomes-based Common Core Curricula for physics, Mostar, 2017.*

↓ ***Figure 7:*** *Indicators for the end of secondary school education in the learning outcomes-based Common Core Curricula technology and information technologies*[15]

Strand 3: Information and communication technologies			
Component 2: Computer system components			
Learning outcomes: 1. student analyses and links HW parts and their characteristics 2. analyses and links SW elements and their characteristics 3. selects and uses computer system components			
Indicators, according to the student's age, for:			
end of 3rd grade (age 8-9)	end of 6th grade (age 11-12)	end of nine-year primary education (age 14-15)	end of secondary school education (age 18-19)
1.a lists and recognises the outer parts of a computer (all the things that can be connected to a computer: USB stick, camera, printer, joystick…)	**1.a** lists and explains basic functions and parts of hardware (e.g. working memory, processor, I/O devices…)	**1.a** explains standard connectors used to link system components	**1.a analyses the impact of specific hardware components on the system performance**
2.a recognises software for specific purposes (drawing, writing, calculation – calculator, games, educational games, music …)	**2.a** differentiates between the systems and application software **2b.** independently installs software	**2.a** differentiates software licences (licenced, trial, open source…)	**2.a analyses software according to it characteristics**
3.a properly turns a computer on/off **3.b** properly initialises and closes down software	**3.a** independently uses operation system (adjust work environment, records and copies a file or a folder to a specific location)	**3.a** independently connects hardware components of a computer system (printer, scanner, camera cell phone, projector…) **3.b** independently uses the network operation system (records, moves and copies a file or a folder to a specific network location)	**3.a applies hardware and software to a specific purpose**

[15] *Learning outcomes-based Common Core Curricula for technology and information technology, Mostar, 2016.*

Conclusion

By drafting the learning outcomes-based Common Core Curricula, using the competency-based approach, the Agency initiated the education reform in Bosnia and Herzegovina. Common Core Curricula for all the strands and subjects within the strands represents the starting point for review and enhancement of the existing curricula. At the same time, student learning outcomes ensure functional knowledge and skills that enhance the competitiveness of our students and ultimately should contribute to students achieving better results at international testing.

However, as the process of the Common Core Curricula implementation in the curricula has a varying dynamic, and in view of the competence for education at the level of the entities, cantons and the Brčko District of BiH, inconsistent application in practice is to be expected. Participation in international studies will certainly provide feedback on the processes that will have to change in order to ensure better quality education.

Also, when it comes to the approach to STEM education, the application of this type of teaching and learning will ensure connections among subjects, including those not part of STEM (e.g. mother tongue, history, music, visual arts, foreign language). There is an expected risk of resistance to this approach by some teachers, however, it can be avoided by continuous training (and support) of teachers and their involvement in all stages of reform.

Full implementation of the reform requires urgent implementation of the Common Core Curricula in the curricula by the competent ministries of education in Bosnia and Herzegovina, that is, urgent review and enhancement of the existing curricula, as well as continuous professional development of all participants in the educational processes.


ALBANIA

Authors

Gerti Janaqi

Gerti Janaqi received a Master's degree in social sciences from University of East London in 2006 and a PhD in psychology from the University of Tirana, Department of Psychology in 2013. Since 2002 he has worked as a lecture at the Department of Psychology and Pedagogy in Faculty of Social Science in University of Tirana. From November 2013 he is the General Director of Institute for educational development, part of Ministry of Education and Sport of Albania. His research covers the themes of educational policy, educational governance, professionalism and organizational behavior, curriculum designation, external and internal quality assurance tools etc. He has coordinated research projects funded by secondary and primary education sector organizations, and several UN agencies.

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Authors

Dorina Rapti

Dorina Rapti received a Master's degree in teaching in social sciences (Department of Psychology and Pedagogy, University of Tirana) in 2003 and a PhD in school leadership from the University of Tirana in 2013. During 1995 - 2007, she has worked as a mathematics teacher/head teacher at the pre-university education system and since 2010 as lecturer at the Department of Psychology and Pedagogy in the Faculty of Social Science at the University of Tirana. During 2010-2013 she has worked in Ministry of Education and Science as head of Vocational Education and Training department and head of teacher training and qualification commission. Since January 2014, she has been the Head of teacher qualification and carrier department in the Institute for Educational Development, part of the Albanian Ministry of Education and Sport. Her research covers the themes of educational policy, school leadership organization, continuous professional development, curriculum and external and internal quality assurance tools. She has co-ordinated research projects funded by World Bank, European Delegation IPA and several UN agencies.

The Institute of Education Development (IED[1]) is a public institution subsidiary to the Ministry of Education and Sport of Albania. The mission of IED is to offer expertise and high level professional counseling to the Ministry of Education and Sport, and the subsidiary institutions of all levels based on the results of scholarly research and educational practices. The IED is responsible for designing the national curriculum, qualification of the teachers, integration of IT in education. Also it offers expertise and counseling for the educational institutions of all levels in the field of curriculum organization and integration as well as in terms of school management and leadership. IED is known in Albania for caring out research about the whole educational policy-making system such as the educational framework, curriculum designation, external and internal quality assurance tools, decentralization and IT integration in education. IED is member of CIDREE (Consortium of Institutions for Development and Research in Education in Europe). IED has carried out different projects in strong cooperation with Cousil of Europe, Unesco, Unicef, UNDP, UNFPA etc.

[1] *IED is called in Albanian language IZHA (Instituti I zhvillimit tw arsimit)*

Abstract

The purpose of this article is to introduce the mathematical competencies defined in the new curriculum to shape students' mathematical knowledge and abilities. In this context the article is based on the article research regarding the importance of mathematical competencies and how to develop them in the student. The main conclusions of this article focus on the fact that teaching mathematics through competencies is effective because:

i) competencies are planned for the normative purposes through clearly defined learning outcomes for what the learner is expected to learn in mathematics;

ii) competencies are used for descriptive purposes by describing and characterizing the current practice of teaching-learning and what can actually happen in the classroom with the student's progress;

iii) competencies as specific and detailed instruments are also used as meta-cognitive support for the teachers and students by helping them clarifying, monitoring and controlling their teaching – learning relationship.

"We must form a person who masters a firm knowledge and not the one who masters more knowledge" [2]

Learning mathematics through mathematical competencies in pre-university education in Albania

Introduction

Mathematics is an universal language, which helps the student understand and take part in the reality that s/he lives. This makes it an important contribution to the intellectual development of the student and the formation of his/her identity. Its mastery is a great value for the integration into society by enabling the development of the student's personality, developing his/her ability to think critically and to work independently and systematically.

One of the most important aspects of the curricular reform is the integration of mathematics with all its areas and cross-curriculum issues with the main purpose of mastering competencies. Mathematics is used in a large number of everyday activities (e.g in media, art, architecture, biology, engineering, computer science, finance, drawings of various objects, etc.).

Even though its applications are different, they cannot be understood without acquiring some basic knowledge of its themes, as these make the student aware of the role of math in everyday life by expanding his/her worldview. Various situations that can be considered in math show how much it relates to other areas. Through mathematics, the student can interpret the quantities using numbers and algebra, interpret forms, space and units using geometry and measurements and finally they can interpret random phenomena using statistics and probability[3].

As a subject mathematics is of a dual nature. On the one hand, through counting, measuring, modeling and geometric concepts, it reveals the world around us and provides the basic language and techniques for managing many aspects, including those of everyday life. On the other hand, with the strength of abstraction, the logical argument and the beauty of authentication, it becomes an intellectual discipline and a source of aesthetic pleasure. Additionally, at present, teaching mathematics presents challenges, some of which are summarized in the following paragraph.

[2] *Montaigne, "On pedagogy", in Essays, 1st Book*
[3] *IZHA 2014 Mathematics Program Grades 3 and 4*

Some issues are related to "problems of reason - why mathematics?", which manifest themselves not only on a social level, but also on an individual level. Certainly, society needs well-educated people in order to actively contribute to its shaping. It needs a highly skilled workforce with active mathematical knowledge and skills to use in a variety of situations and contexts[4]. We must admit (regretfully) that in reality mathematics' popularity is decreasing among the students. This negative trend not only confirms itself during conversations with students and teachers, but also when examining the low number of high school students applying to the math branch[5]. Some people question the usefulness of math for the citizens in general, as we are now experiencing an era dominated by computers, calculators and other technologies.

Another category of problems and challenges has to do with the *implementation*. Some of the most important are related to math teachers, their teacher training and professional development. In accordance with their pedagogical professional development, math teachers should focus on mathematics' didactics, especially in the basic education classes. On the contrary, math teachers for the upper secondary education have a strong background in academic mathematics, but the background of didactics of mathematics is still poor[6]. Problems with the math teachers cause "transition" problems (for the students?) in passing through the various cycles of the education system (eg, the level of basic education in secondary education and later on in tertiary education) by producing significant deficiencies.

Another aspect of institutional differences in teaching mathematics is that *mathematics is perceived and treated differently at different levels*. For the students, the goals and features of the subject seem to vary considerably from one level to another. Reasoning, modeling, the way of thinking, respectively seems to differ significantly from one level of education to another. The main problem in this respect is that different levels of education tend to see themselves as "competitors" rather than as "collaborators" operating with the same overall effort and with the same shared project, namely to enhance and strengthen the mathematical competencies of all students and to shape the way mathematics is taught.

Among this panorama of challenges, *student's progress* in mastering mathematics takes a special place. What do we understand by progress and does this understanding agree with our understanding of the concept of mathematical mastery? This is closely related to another, somewhat wider challenge; *the problem of the evaluation*.

The problem of evaluation consists of two issues: first of all the valid and reliable interpretation of the evaluation, which we perceive as one of the key components of mastering mathematics.

This relates to the design and adoption of assessment tools that measure students' knowledge and skills in mathematics. The use of these instruments should not lead to erroneous results when drawing conclusions about students' mastery of mathematical competencies. The biggest problem here is that the instruments can be manipulated by producing ambiguous results, mainly because of the insufficient validity, which is often sacrificed for the sake of trustworthiness; secondly, the frequent discrepancies between the three components:

i) the ways of evaluation;

ii) subject goals;

iii) teaching- learning mathematics forms[7].

[4] *Niss, M. (1996). Goals of Mathematics Teaching;*
[5] *Babamusta, N ,Some problems of learning math at school*
[6] *Teacher Qualification Results 2008 - 2014*
[7] *Bodin, A. (1993). What Does to Assess Mean? The Case of Assessing Mathematical Knowledge*

There are of course many other challenges and problems in math teaching, which we will have to exclude from this article. However, according to us, the restructuring of the mathematics training system should underlie the basic principle in math learning, which is: *"All students are able to learn math".* Therefore, the new curriculum reform is based on the mathematical competencies.

Mathematical Competencies

Mastering mathematics means possessing mathematical competencies. But what does this mean? In general, possessing a competency (ie being competent) in a personal, professional or social domain means being able to deal with specific conditions and curcumstances pertaining to the essential aspects of that domain. Under these conditions, mastering the mathematical competency means having the ability to understand and judge the usage of mathematics in a variety of situations and contexts outside of the subject field itself, as well as identifying the situations in which mathematics play or can play an important role. Necessary prerequisites, but certainly not the only ones, in order to master mathematical competencies are factual knowledge and technical skills. Indeed, language competencies such as vocabulary, spelling and grammar are also necessary prerequisites. With the new curriculum, mathematics is structured along six competencies, which are mentioned below:

Competency 1: Problem Solving Situation

This competency deals with describing and solving problem situations. On the practical level, these problem solving situations are taken from common experiences of everyday life and on the abstract level they help develop intellectual capacity and creative intuition. Some key indicators are:

- *Determining the data of the problematic situation;*
- *Modeling of a problematic situation;*
- *Implementation of different steps to solve the problem situation;*
- *Validation of problem solving;*
- *Presentation of problem solving.*

Competency 2: Reasoning and Mathematical Approval

This competency caters to the use of reasoning, argumentation and authentication, which are basic aspects of mathematics. Reasoning is based on the logical organization of facts, ideas or concepts in order to achieve a more reliable result than intuition. Some key indicators are:

- *Identification of elements of the mathematical situation;*
- *Usage of mathematical concepts and appropriate processes to the given situation;*
- *Reasoning for the implementation of concepts and processes in the given situation.*

Competency 3: Mathematical thinking and communication

This competency asks students to organise and clarify their mathematical thinking, by using their four language skills, reading, writing, speaking (discussion) and listening. When communicating in mathematics, the concepts, processes and their understanding are reinforced. Mathematical language is used not only in other subjects but also in everyday life. Some key indicators are:

- *familiarity with the language of mathematics;*
- *the connection of the language of mathematics with the everyday language;*
- *interpretation of mathematical concepts.*

Competency 4: Conceptual connection

This competency is about constructing mathematical concepts in order to form a whole, using the dependencies between these concepts. Mathematical reasoning develops the connection between concepts by building and implementing them in the respective mathematical processes.

Competency 5: Mathematical Modeling

This competency is about describing and creating patterns using basic mathematical actions in everyday life situations. Modeling is the process of presenting the real life situation with the help of mathematical language. Via the usage of relevant techniques, a mathematical solution can then be interpreted in real life. Some key indicators are:

- *determining the situation in real life;*
- *mathematical modeling;*
- *finding a mathematical solution;*
- *translation of mathematical solution into real-life situation solutions.*

Competency 6: Using technology in mathematics

This competency is about using technology as a means of solving or verifying solutions as well as collecting, communicating and discovering information.

The organization of math-based competency learning shifts the learning focus from subject content (teacher-centered) to what students need to know and do efficiently in different situations (student-centered). When a student achieves the mathematical competencies, s/he is also developing lifelong learning competencies. For example: Mathematical competency "Problem Solving Situation" includes many of the strategies of solving various problem situations in society and in everyday life. Likewise, with the development of the mathematical competencies, the learner develops competencies in terms of creativity, innovation, information processing, presentation of tasks, group work, effective communication etc.

Learning mathematics with competencies

Classroom students have individual learning startegies, some prefer learning on their own, some in groups, some under the guidance of teachers, some independently, some through concrete tools, and so on. In addition, the subject of mathematics requires students to possess competencies, meaning that they have to acquire concepts, and master respective skills. Both of these conditions dictate the need for different teaching strategies that fit the learning objective and cater to the students' needs.

A well-informed and well-taught teaching - creates the necessary conditions for success and facilitates the work of both teachers and students. Mathematical competencies are interrelated, with a synergy and are developed through learning situations that focus on the active participation of the students. Learners are active when involved in activities, explorations, constructions or simulations of knowledge, skills, and comparisons of results or conclusions. To ensure this active student participation, the teacher should create an atmosphere that makes them feel at ease and more versatile in order to develop a deeper understanding of mathematics.

Moreover, learning maths with the help of competency means that a student has to deal with learning situations in which s/he has to find answers to questions such as "..because...?", "Is it always true...? "," what happens when ...? "etc. In this way s/he is encouraged to reflect on her/his actions and to analyse new situations. Through learning situations, the student explores, applies and integrates mathematical knowledge and skills, acquires the intellectual skills necessary to develop mathematical thinking of thought, becomes aware of his/her abilities and manages to have a certain attitude also with regard to the people around him/her.

Below I am outlining some examples of the competency enforcement.

Competency 1: Problem Solving Situation

A concrete illustration of a learning situation to develop this competency can be:

"Ms. Light has just returned from a one-day trip. She searched in her wallet and without having exceeded two 1000 Lek banknotes, one 500 Lek banknote, one 200 Lek banknote, three 50 Lek coins, one 20 Lek coin, one 10 Lek coin and three 5 Lek coins. She remembered having spent twice before travelling. She spent 1150 Lek on a market and some money for food. When she counted the amount of money in the wallet, she realized that she had almost half the amount of money she had in the morning. How much money did she spend for food while travelling? How much money did she have at the beginning of the trip?

What technique will you use to solve this situation? Why did you choose this technique? Explain why you think you have chosen the most appropriate technique for solving the problem."

Competency 2: Reasoning and Mathematical Approval

A concrete illustration of an activity that helps in the presentation of the addition and subtraction of integers without the need to learn the rules. Then the students themselves can make the deduction of their actions.

"Students create a table and complete it with the « + » and « - » team as follows:

During a competition the "+" team has received 4 points, 5 points and 2 points, while the "-" team has received 3 and 1 points. These points are placed on the table.

+	-
4	3
5	1
2	

Then we add the points of the two teams. Which team is going to win and by how much? How did you do it? What can you summarize? If the game is a draw, then what is the answer?

Competency 3: Mathematical thinking and communication

Some concrete illustrations of typical questions and answers to develop this competency at various educational levels can be:

A: *"In how many different ways can the number 3 be expressed as the difference between two natural numbers?"*

B: *"Infinite because ...."*

→

A: *"If you play chess on a field of 11 to 11 boxes, can there be equal numbers of black and white boxes just as it does in a normal chessboard?"*

B: *"No, because the total number of boxes is an odd number and specifically ...."*

A: *"Is it true that for rectangles with a certain surface you can get some perimeter?"*

B: *"Yes, because ...."*

A: *"Is it also true that for rectangles with a certain perimeter you can get some surface?"*

B: *"No, because each surface is taken for a given perimeter and concretely ...."*

A: *"Is the number 0.999999... the last number before 1?"*

B: *"No, because ....".*

Competency 4: Conceptual connection

A concrete illustration to develop this competency where concepts are intertwined with one another can be:

"Create 14 cards in which the numbers are listed as shown below and put them in rows. The first line contains 4 large numbers and the other rows contain numbers from 1 to 10.

100	75	25	50
8	4	1	
10	7	5	3
2	6	9	

By adding, subtracting, multiplying, dividing the six selected numbers, try to reach the three-digit number you have chosen or approach as close as you can. You can also use brackets to create numeric expressions."

Competency 5: Mathematical Modelling

A concrete illustration to develop this competence, in which a function formula can be modelled, can be:

"A basketball team of your age played matches every Saturday. At the end of the season when the club tour ends, all players go to a fast-food restaurant to celebrate the end of the season. If a hamburger costs 140 Lek, find a way to determine the total cost of hamburgers for a different number of players if everyone buys a hamburger?"

Students start thinking, justifying by addressing players' numbers. They build a chart and make pairing numbers by generating alternative solutions. These number pairs can also be placed in the coordinating network. The most advanced learners can model and suggest a formula using variables e.g. $y = 140 \cdot x$ (where x is the number of players and y is the cost for all hamburgers).

Competency 6: Using technology in mathematics

A concrete illustration of applying technology to maths by conducting a study:

- *"Formulate a questionnaire to collect data about people's opinion about the weather in your city. Ask them to make a forecast for the weather next year.*
- *Arrange the data you've collected and do at least one graph that shows what people think about the weather in your city.*
- *Try to find information about the weather in your city over the past five or ten years. Arrange the data and use the graphs to show the information.*
- *Do the opinions of the people you have interviewed match with the information you have found for the last few years? Explain.*

- *Do you think that data and graphs will be different if you describe the weather in another city?*
- *Can you make a forecast for the weather next year in your city? Where are you based?"*

Conclusion

At the end of the article, we can conclude that the teaching of mathematics with competencies is effective because:

- *First, competencies are planned for normative purposes, through clearly defined learning outcomes for what the student is expected to learn in mathematics.*
- *Secondly, the competencies can be used for descriptive purposes. More specifically, they can be used to describe and characterize the current teaching practice, which can really happen in the class with the student progress. They can also be used to compare the curriculum at different levels of the education system, even in different countries, as well as the relevant achievements.*
- *By trying to improve the competencies, competencies can also be used as meta-knowledge support for teachers and students, helping them to clarify, monitor and control their teaching and learning, respectively.*

The question is how can we motivate, develop math teachers of all the levels of education to effectively implement a new math program and foster the development of the six mathematical competencies of students? Of course this issue remains open.

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FRANCE

Authors

Sophie Soury-Lavergne

For more than 20 years, I have conducted research studies in the field of Dynamic Geometry and Technology Enhanced Learning in Mathematics. The difficulties of technology integration into primary school teachers' practices questioned the role and place of digital technology in the teachers' system of resources. I am studying this question by considering a duo of artefacts, composed of a tangible and a digital tool, as a simplified model of a system of instruments in a didactical situation. It enables to frame research questions related to teachers' resources, design, quality and appropriation as well as to students' learning in the domains of arithmetic or geometry. My approach is also relevant to deal with emergent fields of questions about robots and connected objects for education.

Gilles Aldon

My main research field is the use of technology in mathematics teaching and learning, particularly, the issues of the modifications of teaching and learning, the contribution of technology in the experimental part of mathematics, in the processes of problem solving. I'm working at the French Institute of Education (École Normale Supérieure de Lyon) in the research team EducTice of which I am the director. I am also president of the International Commission for the Study and Improvement of Mathematics Teaching (CIEAEM), which investigates the actual conditions and the possibilities for the development of mathematics education in order to improve the quality of teaching mathematics. The annual CIEAEM conferences are essential to realize this goal. The conferences focus on the exchange and discussion of the research work and its realization in practice and on the dialogue between researchers and educators in all domains of practice.

Abstract

Based on a presentation of the new French mathematics and technology program, the chapter focuses on the teaching or use of computer science and presents case studies from projects where computer science is involved: first, when a system of connected objects allows the exploration and design of mathematical learning situations: the OCINAEE system is a set of interacting devices, either tangible, such as cards or dice, or digital, such as tablets and smartphones. The connection between the two classes of objects is operated by a mobile robot that can read physical elements such as cards or any other printed material. Second, when computing is a school subject, we present three examples showing how unplugged computer science can achieve different goals with the same situation, if only the situation is studied more and more deeply. Based on game situations, the resolution leans to an understanding of fundamental computer science concepts such as termination, complexity and proof of an algorithm.

Contribution from Gilles Aldon and Sophie Soury-Lavergne
French Institute of Education, ENS de Lyon

The French curriculum for mathematics and technology

Context

The French national curriculum has been deeply reformed since September 2016. The reform does not only apply to existing teaching contents (syllabi) but further extends to (structural) organizational changes within the school itself, with a special focus on interdisciplinary approaches to content and class organization. All types of schools are concerned, from nursery school to K9.

Students' mandatory education, beginning at age 6 and finishing at age 16, is divided into 3 cycles, spanning the course of 3 years each:

- *the aim of the second cycle (K1 to K3) is for students to gain fundamental knowledge and competencies;*
- *the aim of the third cycle (K4 to K6) is to consolidate this knowledge and these competencies in order for the students to be able to master them;*
- *the aim of the fourth cycle (K7 to K9) is to deepen previously acquired knowledge and competencies, allowing students not only to become well-educated members of French society, but also to pursue further studies and enhance their lifelong personal development.*

The first cycle concerns nursery education, which is not mandatory in France, even if more than 95% of the 3 year-old pupils attend nursery school.

The special feature of the new third cycle is that it now bridges primary school and the lower secondary school (called *collège* in French). This means that the evaluation of students' achievements in learning now has to span the two last years of primary school and the first year of lower secondary school.

The new and detailed French curriculum, which has been released in November 2015 and has been implemented since September 2016, can be downloaded here:

http://www.education.gouv.fr/cid95812/au-bo-special-du-26-novembre-2015-programmes-d-enseignement-de-l-ecole-elementaire-et-du-college.html

Intention of the curriculum

The French curriculum follows two different pedagogical strands. While the first one focuses on the competencies – the common core of knowledge and skills – defining seven main key domains of competencies, the other one focuses on the subjects to be taught, among which sciences and mathematics – the "program". Teachers are supposed to organize the teaching of their subjects in such a manner as to make pupils develop the subjects' core as well as specific knowledge defined by the program. The aim is to organize teaching in a more coherent way, allowing each subject, with its specific features, to contribute to the development of students' competencies. Moreover, interdisciplinary projects, where teachers of different subjects are present, are scheduled in students' agendas. Therefore, it should favor a more integrated teaching of STEM, beyond individual subjects' boundaries and toward more interdisciplinarity.

Another key feature of this curriculum is the introduction of computer science as a new teaching topic.

Sciences, mathematics and technology contribute the following five domains of competencies to the common core of knowledge and skills:

1. *Languages to think and communicate: Just like the development of the French language is a necessary tool for students to understand and communicate with the world, mathematics, computer science and sciences also provide languages that are useful to solve problems, to generalize solutions, to deal with data, to read and communicate results, to represent experiences, objects and phenomena... Therefore the "common core" encourages teachers to consider that mathematics and sciences are providing a language that every subject can help to construct and use.*

2. *Methods and tools to learn: the use of numerical tools and the collaboration between students in order to drive a project are competencies that can be developed in every subject, especially in sciences and mathematics. Dealing with sources of information, questioning their relevance and validity, mastering digital environment to edit image, text, sound… lies at the heart of every subject. Moreover, using CAS, numerical data and computing software is specific to mathematics. Computer science taught in mathematics and technology allows to deepen the use of digital tools.*

3. *Development of personal identity and citizenship: the whole teaching content must contribute to the development of self-confidence and mutual respect. Mathematics and sciences contribute to the development of judgment, critical thinking and truth seeking, through the notions of argumentation and proof.*

4. *Natural and technical systems: observing the real world, in sciences but also in sport, art or media for instance, raises questions as well as the necessity to look for answers. Sciences, technology and mathematics try to solve these questions by providing powerful models and systems of representation. The sciences provide fundamental tools to understand, to increase awareness and to adopt a responsible behavior in the fields of environment, health and technological growth. In mathematics, knowledge about numbers, magnitudes and measurement of time and space, scales and proportionality, algorithms etc. is key to understanding*

the world and to solving problems with different methods, including trial and error, conjecture and validation. STEM is a major contributor to the development of competencies of this domain.

5. *Representations of the world and human activity: the objective is to make students build a personal and shared culture, also in STEM, by understanding the relationships between sciences, technology and societies. Their scientific and technological culture will help them to measure the effect and the sustainability of innovations.*

STEM and teaching algorithms and programming

This new content does not aim at training specialists of computer science, but aims at providing students with decoding tools in order to understand the evolution of the digital world. It aims at giving them the opportunity to acquire competencies and methods, which in turn should allow them to develop computational thinking.

The mastering of programming language is not an objective of this teaching, but by practicing this language, students discover methods of inquiry and develop modeling and simulation skills.

There are two approaches to computer science, which are rooted in two different epistemologies: a theoretical point of view rooted in mathematics epistemology (the computer as an idea, a legacy of Turing's thinking, instead of the computer as an artifact); a more experimental point of view, inherited from experimental and engineering sciences (the computer as an artefact, implementing modeling and abstraction processes in different semiotic systems).

As a consequence, the two different approaches are present in the curriculum, in the teaching of mathematics as well as in the teaching of technology:

- *One approach focuses more on the understanding of algorithms and their translation into a programming language (mainly Scratch or any other visual programming language).*

  This teaching aims at developing the following competencies:

  – analyzing a complex problem and being able to split it up into sub-problems,

  – pattern recognition,

  – generalization and abstraction leading to structured and reusable instructions,

  – elaboration of algorithms using fundamental concepts of algorithmic as event-based programming, parallelism,...

- *The other approach focuses more on the possibilities of connecting objects and devices (robot, connected objects,...) as well as on learning other contents.*

  This teaching aims at using technological tools in a complementary fashion:

  – study of technological systems aiming at understanding how a technological system is able to communicate with its environment,

– *data coding that makes it easier to search the data, to make comparisons and to identify any patterns that require further investigation.*

Following the interdisciplinary aim of the curriculum, these two approaches are taught in parallel in mathematics and technology courses: two teachers working together on a single object and integrating his/her own viewpoint. This is a transposition to the school of a specificity of computer science, a “[...] multifaceted field that encompasses scientific and engineering aspects which are manifested in algorithmic problem-solving processes, for which computational thinking skills and sometimes also artistic and creative thinking are required” (Hazzan & al., 2011 p. 24). This transposition is based on the particular competencies promoted in the two disciplines.

In mathematics, the same six competencies, searching, modeling, representing, reasoning, calculating and communicating, are laid out for each cycle. Example for cycle 3:

- ***Searching.*** *Solving problems by picking and organizing necessary information from various supports: texts, tables, diagrams, graphics, drawings, sketches, etc. Being involved in a process, observing, questioning, manipulating, experimenting, raising hypothesis by using tools and already known mathematical procedures, by developing a reasoning adapted to a new situation. Testing and trying several solving paths.*
- ***Modelling.*** *Using mathematics to solve some problems of the everyday life. Recognizing and distinguishing problems belonging to additive situations, multiplicative situations, proportionality. Recognizing real situations that can be modeled by geometrical relations (alignment, parallelism, perpendicularity, symmetry). Using geometrical properties to recognize objects.*
- ***Representing.*** *Using tools to represent a problem: drawings, sketches, diagrams, graphics, expressions with parentheses,... Creating and using diverse representations of simple fractions and decimal numbers. Analyzing a plane figure under different aspects (surface, outline, lines and points). Recognizing and using basic coding elements of a plane figure or a solid. Using and creating representations of solids and spatial situations.*
- ***Reasoning.*** *Solving problems requiring to organize multiple competencies or the elaboration of a process that combine steps of reasoning. In geometry, smoothly going from perception to control by instruments in order to reason only on figures properties and relation between the objects. Evolving in a collective investigation by taking into account the others’ points of views.*
- ***Calculating:*** *Calculating with decimal numbers, exactly and approximately, by using appropriate strategies and techniques (mentally or with computing algorithms). Controlling the plausibility of his/her own results. Using a calculator to find or check a result.*
- ***Communicating:*** *using progressively an appropriate language and/or adapted notations in order to describe a situation or to set out an argumentation. Explaining his/her own approach or reasoning, understanding others explanations and arguing.*

In technology, the competencies appearing in cycle 4 are:

- ***Practicing scientific and technological inquiries.*** *Formulating scientific questions, establishing hypothesis in order to solve a problem, elaborating experiences, using observational tools, interpreting results and drawing a conclusion, communicating both results and processes, identifying and choosing adapted notions or models in order to enter a scientific process.*
- ***Designing and creating.*** *Being able to draw an experimental protocol.*
- ***Appropriating tools and methods.*** *Identifying and organizing tools and techniques in order to keep a research memory (orally or written).*
- ***Using languages.*** *Describing, using adapted tools and languages, the structure and the behavior of objects. Applying the basic principles of algorithms and codes in order to solve problems.*
- ***Using digital tools.*** *Simulation of the behavior and structure of objects, organizing and storing numerical data, reading, using and producing representations of digital objects, driving a connected system locally or remotely, modifying or parameterizing a connected object.*
- ***Adopting an ethical and responsible behavior.*** *Improving good practices regarding connected objects and analyzing environmental impact of an object and its components.*
- ***Self-positioning in space and time.*** *Bringing together objects of a same family, linking technological developments to inventions and innovations that mark breaks in technical solutions.*

Technology and computer science

Computer science can be seen both as a tool for teaching and learning mathematics and as a body of knowledge to be learnt, in the courses of mathematics or technology. In both cases, digital tools are involved. Their role and place has to be analyzed.

In this section, we expound on two examples, stemming from our work in research projects about mathematics education and computer science culture:

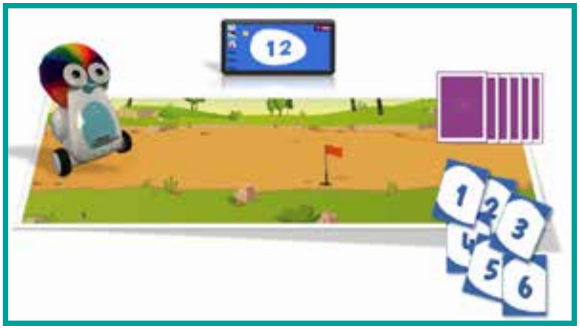
- *OCINAEE Connected objects and Digital Interfaces for Learning at Primary School and problem solving in mathematics,*
- *Unplugged computer sciences.*

Mathematical games with a robot at primary school

The OCINAEE project (2014-2016) – Connected Objects and Digital Interfaces for Learning at Primary School – was aimed at exploring and designing mathematical learning situations with a system of connected objects. The OCINAEE system is a set of interacting devices either tangible, like cards or dice, or digital, like tablets and smartphones. Connection between the two classes of objects is propelled by a mobile robot that can read physical elements such as cards or any printed material. The robot itself has properties of both worlds, the tangible and the digital. Like any concrete manipulative, it is an artifact with mechanical and physical properties, mainly through its movements. However, it is also a digital artifact because its behavior results from instructions given by a digital environment either automatically generated or piloted by a user.

The OCINAEE system provides didactical situations for the learning of mathematics based on the manipulation of tangible and digital objects and problem solving. Four different games have been designed with the OCINAEE environment, addressing some main mathematical content for primary school like place value, addition of integers and decimal numbers, spatial knowledge and codes for positions and trajectories in a plane.

Designers had to choose between tangible or digital devices for each kind of action and feedback, which should support the students in their problem solving among such a complex environment.



↑ ***Figure 1:*** *Some of the connected objects of OCINAEE system for the game "target number": moving robot, smartphone displaying the target number 12, game board and sets of cards.*

For instance, in the game "target number", students have to choose 3 numbers out of 6 whose sum is the target number. With the card version of the game, the target number is displayed on a smartphone and the numbers to be added are printed on cards with their symbolic writing. Students have to present cards to the robot. Then the robot moves on a line toward the target and stops before or after the target according to the sum. It also announces if the number of presented cards is correct or not. The tablets version of the game provides students with virtual representations of numbers, that are manipulated on the screen of a tablet. To implement such a game within OCINAEE devices, designers had to create different kinds of feedback (Mackrell et al. 2013) as well as to choose whether elements should be tangible or digital objects. For instance, the movement of the robot on the board is a tangible feedback that informs the students about their answer (too small or too big), telling them something about their solving strategy.

Moreover, even though it is a rather simple kind of feedback, this straight movement of the robot can mediate the notion of number line (Mandin et al. 2017). The same feedback is also an evaluation, since reaching the target point indicates success. Another example of feedback is the fact that the robot's eyes flash each time a card is presented, although no indication of the numbers of cards already presented is revealed. This choice is the result of a didactical analysis: students need to know that the system takes a card into account (direct manipulation feedback) but they have to deal with the fact that the result is a sum of three terms. They have to control it and they can succeed if they manage the cards and separate the ones they have already presented from the others.

Our first results show that students' solving strategies differ with tablets and cards, the spatial organization of the cards requires a specific management and control, helping some students in the solving strategy. Moreover, their solving strategies differ according to the way and the aim in which they use the system.

Some of the students interact with the system to prove they have correctly solved the problem, leading to few trials and interaction with the robot.

↑ ***Figure 2:** OCINAEE devices for the game "Journey in the plane"*

Others are looking for help and hints to progress in the solving strategy, interacting a lot with the robot and therefore risking failure.

In the game named "Journey in the plane", the students have to control the positions of the robot and of other elements on a plane. The plane is tangible, represented by a board that exists in two different versions: a squared plane and a virgin one. To drive the robot, students can choose between two ways to indicate the robot's direction: an absolute piloting device, that refers to the plane orientation (four different instructions, each being one step toward one of the four sides of the board), and a relative piloting device, that refers to the robot orientation (three different instructions, one step forward, turn to the right, turn to the left). It generates two ways to code the robot's trajectories and asks the students to build relationships between the orientation of each device (tablets, robot, board), even the board itself when it is virgin and the trajectory code. Therefore, the OCINAEE environment enables to design learning situations that combine knowledge related to spatial orientation and first elements of coding. It provides an environment in which the model of a squared plane is a relevant tool to solve the problem of controlling the position and the trajectories of a robot.

Another key element of a successful strategy is the information collected by students during their trial and the way they choose to keep this information. It provides roots for coding the positions and the trajectories of the robot in the plane and for coding instructions of movement. This game creates a didactical situation in which the mathematical knowledge (orientation, plane mapping, code) is a key element of solving strategy.

In a broader perspective, the example of the OCINAEE robot and the set of devices, provide an environment with sufficient feedback to support problem solving strategies in mathematics and the development of key mathematical competencies such as searching, representing, modeling, calculating.

Computer science as a school subject

Computer science as a new school subject can be related to the use of computer or programmed robots but can also be thought to develop particular skills that are grouped under the term of computational thinking (Wing 2006). In order to develop such skills, it seems necessary to move past the difficulties of learning a programming language. In this sense unplugged computer science offers many opportunities to meet informatics concepts. But it is also, on a different level, a way to make students think about algorithm, aside from any language constraint and to develop computational thinking. The following examples are based on games that can be played both by primary pupils and secondary students. The two first games were taken from the book “Récréations mathématiques” by Edouard Lucas (1891/1960) and the third from a French association of computer scientists wishing to enhance computational thinking.[1]

- *The Hanoï tower: In order of their decreasing diameters, different sized disks are piled up onto a rod. The game consists of swapping the whole tower from one rod to the next (the number of rods that may be used is limited, usually 3), following the two rules: only one disk can be moved at a time and no disk must be placed on top of a smaller disk.*
- *The men with hats: three identical pieces representing a man with a hat and three identical pieces representing a man without a hat are placed on the two opposite sides of a checked pattern of 7 squares. The game consists of changing the position of the man with a hat and the man without a hat, following two rules: a piece can move on an adjacent square if it is empty, and a piece can jump over only one piece at a time.*
- *The inflexible chef: at the end of the day a chef still has pancakes of different sizes with one side burnt left over. Before leaving the restaurant, the chef wants to place the pancakes on a stack, starting with the larger ones at the bottom and finishing with the smaller ones on top. The chef also wants the pancakes to have their burnt side facing up. There is only one possible movement: to introduce a spatula between two pancakes and turn all the upper pancakes over. Is it possible to create the pancake tower?*

In each game, the goal is to succeed that is to say to inverse the position of men with hats and men without hats, to change the position of the tower and to create the pancake tower; but also students have to count the number of movements needed to win the game. Additionally, regarding the students’ level, they can be asked to prove that one algorithm is the most efficient. For example, the “men with hat” game can be solved using only 15 movements. And it is also possible to prove that the number of movements is greater or equal to 15, which finally proves that the 15 movements algorithm is the best.

When students play the games and try to highlight a general algorithm allowing them to win, they deal with the three fundamental computer science principles which are correctness, termination and complexity. These principles are illustrated and explained with the help of these games. The correctness and the termination principles can result from a formalization of the students’ experiences with real objects.

[1] *https://files.inria.fr/mecsci/grains-videos3.0/videos/crepier_psychorigide-H264_1024x576_5Mbit.mp4*

Particularly, asking students not to solve the problem directly, but instead instructing a peer how to solve the game, forces them to see the necessity of a precise language, thus leading them to the idea of computation. The complexity can be addressed by the number of movements. A particularly interesting feature of these games is that the complexity of the first is exponential, the second is quadratic and the third is linear.

These three games provide a fantastic introduction to computational thinking linked to mathematics. But it is not the only way to present algorithm and computer science. A balance between this approach, grounded on tangible artifacts, and a practice with digital artifacts within a STEM approach should allow students to build a sufficiently high culture to face our actual digital world.

Conclusion

This study by the French educational institution, has hereby put forth the main principles of the 2016 French reform, with a will to renew the way STEM subjects are taught and to make them more inclusive. The unsatisfactory French results of the latest Pisa evaluations and the need to change teaching practices by further exploiting technological possibilities, play in favor of this reform. Opponents argue that individual subject knowledge risks losing in importance and that the educational organization may not be acceptable in schools. The coming years will certainly yield some interesting feedback that could serve as a productive research field and help evaluate this new curriculum.

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NORWAY

Authors

Ola Berge

Ola Berge is a researcher at the Department for Research and International Affairs, at the Norwegian Directorate for Education and Training. He holds a PhD from the Department of Informatics at the University of Oslo, and his field of expertise is learning technologies and digital competencies. He has worked in the field of ICT and learning as a research manager at both the Norwegian Centre for ICT in Education and ITU at the University of Oslo. He has also worked on technical aspects of digital learning resources as manager of the Norwegian Secretariat for Standardization of Learning Technologies.

Ove Edvard Hatlevik

Ove Edvard Hatlevik is a Professor at the Faculty of Education and International Studies, OsloMet - Oslo Metropolitan University. In recent years, he has published articles on pupils ‘digital divisions and teachers’ use of digital technology in reputable scientific journals. Currently, he participates in research on Teaching Methods, Teacher Education and Educational Technology. His current projects are ‘Developing ICT in Teacher Education’, ‘Developing collaboration between Teacher education and practice schools’ and ‘Fairness in Assessment’.

Abstract

This article presents the ways in which information and communication technology (ICT) and informatics skills are represented in primary and secondary school curricula. The chapter outlines central policy initiatives on ICT in education. A case study is presented to illustrate how digital technology can be used to provide specialised education to students located in sparsely populated areas. The pilot project 'The Virtual Mathematics School' is aimed at providing Internet-based education for highly motivated and skilled students in lower secondary school by offering a course in mathematics from the upper secondary curriculum. The five-year project utilises a flipped classroom approach combined with technology for teaching and student collaboration. The chapter outlines didactical, technological, legal and organisational issues encountered during the pilot.

Promoting motivation through technology-mediated mathematics education

Introduction

Equity is a central principle in the Norwegian educational system. Norway is a nation with a population of 5.3 million and an area a bit smaller than Germany (pop. 80 million) but larger than Poland (pop. 38 million), and a terrain described in the CIA World Factbook[1] as 'glaciated; mostly high plateaus and rugged mountains broken by fertile valleys; small, scattered plains; coastline deeply indented by fjords; arctic tundra in north'. There are many small communities and people living in sparsely populated areas, which can sometimes make it a challenge to provide equal opportunities for all students in primary and secondary education. While digital technology might reinforce or introduce new social differences—digital divides—it might also be used for inclusion (e.g., Livingstone & Helsper, 2007).

In this chapter, we present a case study of how information and communication technology (ICT) can be used to strengthen equity and find ways to overcome challenges posed by geography and population density. But first, we provide some context by briefly outlining the Norwegian educational system. We also specify the conditions for providing technology-mediated education by describing how digital technology is represented in the curriculum and outlining the digital situation in Norwegian schools. The case study is presented as a description of the virtual school and includes some important insights gained with respect to organisation, technology and teacher experiences. The chapter is concluded by a section on the how the knowledge and technology from the pilot project are utilised.

[1] *https://www.cia.gov/library/publications/the-world-factbook/geos/no.html*

The structure of initial education and training in Norway

The educational system of Norway comprises kindergarten, primary school, lower secondary school and upper secondary school. The right to an education in Norwegian schools is primarily based on a child's birth year. Children in Norway are legally entitled to 13 years of education, beginning at age six. Each year, approximately 63,000 children enter the first level of primary school. Almost 100 percent of the children start when they are six years old. It is not very common to start earlier or later than your age cohort.

Primary school comprises grades 1–7 (ages 6–12). It is common to distinguish between the lower primary level (grades 1–4) and the upper primary level (grades 5–7). There seems to be a stronger emphasis on academics in the upper primary level compared with the lower primary level. Students experience more complex tasks when they proceed from the lower primary to the upper primary level.

Lower secondary school comprises grades 8–10 (ages 13–15). Most children change class and receive a new form teacher when moving from the upper primary level to the lower secondary level. They also change schools, so that they experience a transition from being the oldest at their primary school to being the youngest at their lower secondary school. In lower secondary school, the students also undergo summative assessment. They receive a matriculation certificate from the lower secondary school at the end of grade 10. This is the basis for applying for admission to upper secondary school.

About 191,000 pupils are enrolled in upper secondary education and training. There are two main tracks in upper secondary school. First, the programme for general studies comprises three levels (ages 16–18). This track can lead to a university and college admissions certification after level 3. Second, the vocational education program comprises two levels (ages 16–17), followed by two years of apprenticeship. The vocational education program could lead to a university and college admissions certification, provided the student completes a supplementary level.

The national curriculum comprises competency aims for all subjects at the end of the 2nd, 4th, 7th and 10th levels, in addition to specific competency aims at each level in upper secondary school. The subject of mathematics is introduced at level 1 in primary school. The pupils have a common curriculum in mathematics up to lower secondary school. However, the curriculum emphasises that the teaching is adapted to the students' needs and interests. This means that students in the same class can be assigned different tasks and, accordingly, progress at different rates. In upper secondary school, there are different strands in mathematics; it is also possible to specialise in mathematics.

Digital technologies at Norwegian schools

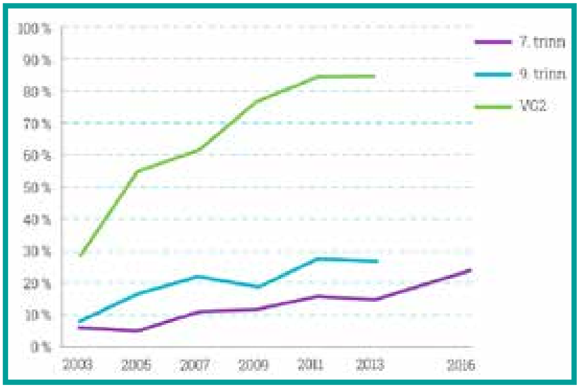
The curriculum: Digital competency as a basic skill

Since 2006, five specific domains (reading, writing, numeracy, speaking skills and the ability to use ICT) have been recognised as basic skills and competencies in the Norwegian curriculum. These five domains are defined as transversal and they are embedded in the intended learning outcomes throughout the entire curriculum (Norwegian Directorate for Education and Training, 2012).

Specific competency aims are developed for each subject. Some of these competency aims contain descriptions of using digital tools and media for learning purposes (i.e., draw a graph, use an online syllabus, evaluate online information, use technology critically, develop awareness of personal safety). For example, as part of the subject of mathematics, there are competency aims that describe the use of ICT in mathematics in 7th or 10th grade. However, there are also competency aims in mathematics without any explicit reference to the use of ICT tools. Additionally, each subject has a description of what ‘digital skills’ means with regard to the particular subject, along with indications of how the use of digital tools can enhance students’ learning, understanding and achievement. For example, digital skills in mathematics ‘involves using digital tools for learning through games, exploration, visualisation and presentation’ (Norwegian Directorate for Education and Training, 2018).

Use of digital technologies

Norwegian schools are, on average, relatively well equipped with respect to digital technology, compared to schools in other European countries (Wastiau et al., 2013). There is, however, considerable variation among schools with respect to infrastructure and the quality of the equipment (Egeberg, Hultin, & Berge, 2016). It is therefore not a given that students at any school and in any grade can participate in activities that have to meet certain technical requirements. The Monitor school survey is a series of studies that maps out the digital situation in schools; it has been conducted biannually since 2003. The 2016 study shows that two-thirds of the 7th graders use a computer or a tablet in school 0–3 hours weekly. Figure 1 shows the percentage of students in grades 7, 9 and 12 (second year of upper secondary) that use computers or tablets for four hours or more per week. Even though there is an increase for the 7th graders from the previous study in 2013, the usage is still lower in 2016 than it was for the upper secondary students back in 2013.



↑ ***Figure 1:*** *Portion of students in grades 7, 9 and 12 (second year of upper secondary) that use computers or tablets for four hours or more per week.*

The 2016 Monitor school study reinforces the indications from earlier studies that digital technologies are used less in mathematics than in many other school subjects. Roughly half the students state that they use ICT for half an hour or less per week in mathematics in school, and 16% report that they never use ICT at school in the subject. Using technology at home can, to some extent, compensate for not being able to use it during school hours, and almost all students report that they have access to a computer or tablet for schoolwork at home. But we have seen that such compensation is not the case for a number of the students in this study. Eleven percent of students do not use computers/tablets in mathematics, either at home or at school.

A test in digital competence was included in the survey; half the items were about digital competencies in mathematics, especially on the use of spreadsheets. The mathematics part of the test was clearly more difficult for the students than the general part. The activity of solving exercises was clearly set apart as the activity in which most students used computers or tablets in mathematics. Even though most students expressed a positive attitude towards many aspects of technology use in mathematics, the students' use of ICT in mathematics follows a different pattern from the use we have studied in other subjects and more generally at school.

Recent developments

In August 2017 the Ministry of Education launched a new strategy for digitalisation of primary and secondary education, for the period 2017–2021 (Ministry of Education and Research, 2017). The strategy's main aims are that the students will have the digital competence they need to succeed in life, studies, work and citizenship, and that ICT are well utilised in the organisation and implementation of education and training to improve the students' learning outcomes. The central challenges outlined in the strategy are the students' digital competence, the teachers' professional digital competence, the availability of high-quality digital learning resources, ICT infrastructure and research and development. The school owners, the municipal and county authorities and private school owners are responsible for providing education and training in agreement with legislation and regulations. A comprehensive effort in ICT in education must include the commitments from local and regional authorities and acknowledge that school owners make different choices based on local priorities. At the same time, an overall national plan giving direction to the local responsibility is also necessary. The strategy for digitisation is an instrument in the ministry's support for the school owners' planning and implementation of ICT-initiatives based on their local needs and requirements. Over the last decade, a lack of coherence has developed between the school objectives and the subject content in schools due to the overload of content in the curriculum (NOU 2015:8, 2015, p. 12). It is therefore an ongoing project to revise the subjects in school in order to facilitate good learning processes and contribute to pupils' in-depth learning and progress in understanding the content of the subjects. This is necessary to stimulate curiosity, understanding and help to utilise students' learning potential. The Official Norwegian Report NOU 2016:14 (2016) identified that many students with higher learning potential did not receive any academic challenges based on or related to their own academic capabilities. The schools and municipalities have resources available to deal with different rates of progress, but this is used to a different extent. There is an ambition with the ongoing project to renew the subjects in school, which could lead to better learning and better utilisation of students' learning potential. Appropriate digital competence and conscious use of digital technology could provide better learning opportunities for groups of students across the country.

The Virtual Mathematics School

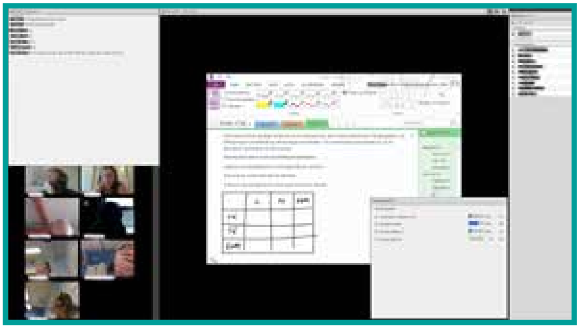
The Virtual Mathematics School (VMS) was established as a pilot project in 2011 and is still ongoing as a pilot. With a background in a white paper on lower secondary education entitled Motivation, Mastering, Opportunities (Ministry of Education, 2011), the Norwegian Centre for ICT in Education (now part of the Directorate for Education and Training) set out to identify how a net-based solution can provide adapted education in mathematics for students in lower secondary school.

The project targets both high-performing and low-performing student groups. In this chapter, we will focus on the course designed for high-performing students. Some of these students might encounter challenges in their regular math classes, as it can be difficult for a teacher to provide education adapted to all levels of ability present in a 30-student classroom.

Some schools arrange for high-performing students in 10th grade to follow education in the first year of upper secondary education. One of the numerous challenges with such an arrangement is that almost no upper secondary schools are located in proximity to schools providing lower secondary education, making it necessary for students to travel between schools. Outside the most densely populated areas of Norway, the distances between individual schools often make such organisation unfeasible. The VMS pilot project sought to overcome the challenges with respect to distance while maintaining the beneficial effects associated with this approach by providing a virtual school. The mandate of the project was to provide recommendations to the ministry on a broad range of aspects regarding the establishment of such a school, including legal, organisational, financial, technological and pedagogical issues. In presenting the VMS in this chapter, we will outline the nature of these issues and how they were resolved throughout the pilot project.

The Virtual Mathematics School is built around the pedagogical approach of a flipped classroom. In short, the flipped—or inverted—classroom imply that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa (Lage, Platt, & Teglia, 2010). Class time is typically devoted to working through problems, advance concepts and engaging in collaborative learning, while instruction takes place at home where the students watch teacher-created instructional videos (Tucker, 2012). The guiding question is: What is the best use of face-to-face time in class?

The three main components of the VMS flipped classroom are e-lessons, self-assessment, and virtual classroom sessions. The e-lessons cover the complete curriculum of the subject, containing short video recordings of the teacher, subject matter from textbook publishers, animations and exercises. After completing an e-lesson, the students are expected to complete a self-assessment in which they report what parts of the material they found difficult and would like to receive help on. The student response is collected and presented to the teacher in a report that is used in preparing for the virtual classroom sessions. The virtual classroom is built on a video conferencing system that facilitates teaching and communication with many students simultaneously and in real-time. An example of the set-up is shown in Figure 2. Important features include the display of the participants' video feeds (left bottom window), audio conferencing, text-based group chat (left top window) and the teacher's shared screen, the 'digital whiteboard' (middle window).



↑ ***Figure 2:*** *The virtual classroom*

The students participating in the pilot were divided into approximately 15 groups, with 15–30 students in each group. During the school year, the students received the required 140 hours of teaching in the mathematics course. During a typical school week, students went through one e-lesson and one self-assessment at home, for a duration of 45–60 minutes, and then two half-hour virtual classroom sessions at school.

Organisational issues

In the Norwegian educational system, lower secondary education is provided by municipal authorities, while upper secondary education is provided by county authorities. Providing upper secondary education to students in lower secondary schools thus involves coordination between school owners at different administrative levels. Furthermore, the Norwegian Education Act stipulates that it is the school owner who is responsible for the quality of education, and that a governmental agency cannot be a school owner. The question of institutional affiliation—who should own the Virtual Mathematics School—is therefore not straightforward. An important challenge for the pilot project was to explore how to organise the educational service without requiring a legal amendment. The option chosen for both carrying out the pilot project and the recommendation for a permanent VMS was to organise the educational service as infrastructure owned by a government agency and offered to municipal and county authorities as a service. This solution implies that the responsibilities of both municipal and county authorities does not change.

The county authorities that use the VMS to provide education to lower secondary students are responsible for allocating teaching staff, formal student enrolment and student assessment and other educational processes. The municipal authorities who decide to use VMS as a supplement to their mathematics education for some of their students are responsible for coordinating the VMS-based activities with other school-based activities, as well as providing the students with the required equipment for participating in the VMS. A governmental agency is responsible for developing and operating the VMS in terms of the conceptual approach, the technical platform, content provision, and some administrative duties. The VMS is thus not a school per se, but an infrastructure (systems, technology, content) and a service (support, documentation for assessment, teacher training, administration). The main advantage of this organisation is that it does not require any legislative changes, making it an attractive option for a permanent solution. One consequence, however, is that students might not get equal opportunities for participation as this depends on whether the authorities in their county have decided to provide VMS or not. Another disadvantage of this model is the split responsibility between providing education and providing the platform for education, making it challenging for the governmental agency to ensure consistent quality across the entire 'school' service.

The number of students admitted to the VMS for each school year has been 300–400 during the pilot phase of the project. The enrolment of students is usually initiated by their mathematics teacher, but it is the students themselves—in consultation with their parents and teachers—who make the final decision. Participation is optional for the students. In deciding the size of the school for a permanent solution, one can use the number of students obtaining the highest level of mastery on the national calculus test, which is about 10%. But also considering that the eligible students should have completed the 10th grade syllabus before joining the VMS brings the estimated number of candidates down to about 1,000 for each cohort. Experience with forced-pace education for students attending classes in nearby upper secondary schools shows the dropout rate is a significant challenge, and this issue was also evident in the VMS pilot. The evaluation of the first pilot year (Tømte & Sjaastad, 2014) clearly showed that high mastery of the subject matter was not sufficient for students to complete the course; available time was also of essence. Many students in the target group have busy schedules, participating in sports or other leisure activities. The real-time virtual classroom lessons were scheduled after regular school hours to avoid conflict with the time tables for other subjects, as the VMS classes were made up of students from many schools. In order to ensure that students signing up for the VMS considered the implications of participating, an online self-reflection tool was developed. The goal of providing this tool was to reduce the number of dropouts. The dropout rate has stabilised around 50% in recent years. This is still a high number and entails challenges with respect to determining the size of the VMS as well as other factors. It is therefore an objective in the continued work to reduce this number, and better accuracy in recruiting students is one issue that can be addressed.

One other issue that relates to sizing and organisation of the VMS is the group size. In the original concept, the students were divided into groups of 15–30 for the real-time sessions. During the year, the groups were gradually reduced to about half that size due to dropouts. In order to investigate opportunities for a more cost-effective VMS, a new model was introduced for some of the students in the 2016–17 school year. Based on the observation that not all virtual lessons were intensive in terms of student activity and interaction, the notion of large groups was introduced. In one of the two weekly real-time sessions, the group size was increased to 60–70 and the didactical approach was modified to concentrate the most active student activities in the small-group session. In an evaluation of the pilot (Sjaastad, Siddiq, Ulriksen, & Tømte, 2017), the potentially negative impact of the increased group size were found to be small. Consequently, this will be the recommended model for future implementations of the virtual school.

Technological issues

The central component of the VMS technical platform is the Moodle learning management system. Students and teachers log on to the VMS Moodle in their web browser to access learning content and the various tools they have available. This is where the education is organised. Another component is the virtual classroom, built on the Adobe Connect video conferencing system (shown in Figure 2). In addition, there is a dedicated video server for the teacher-created e-lessons, a user administration system and various external services containing digital learning resources from publishers and other educational service providers. All these components are available for the users through single sign-on.

The students participating in the VMS are required to use a computer with a web camera, a microphone and headphone and an Internet connection. In addition, there are some software requirements. In order to streamline the process of checking whether a computer is set up properly for use in the VMS, an automated check was developed. The students or school IT staff access the test on the Moodle site, and a check for plug-ins, versions and software installations is executed. Student feedback from the evaluations (Sjaastad et al., 2017; Tømte & Sjaastad, 2014) indicates that the technology worked quite well, but about a quarter of the students had problems with audio and Internet connections. Forty percent reported that they used their own personal computer for VMS, 30% used the school's PC, and 30% used both their own and a school-owned computer. The VMS software requirements did not match the standard configuration at many schools. Early in the pilot period, some schools did not provide dedicated computers for the VMS students, resulting in repeated technical problems for these students. The teacher interviews reveal that early on in the school year, the real-time lessons are troubled by technical problems, mainly issues regarding use of audio and video. Many students are not used to video conferencing with many participants and need to be reminded of techniques like muting the microphone when they are not addressing the others, for example. It usually takes a few lessons for everything to run smoothly.

The teacher set-up includes an extra computer for displaying the student's view in the virtual classroom as well as an interactive digital drawing board with a pen—a digital whiteboard. The teachers report that the equipment and software work well; their main concern is the quality of the students' audio and video during the real-time lessons.

The VMS pilot project was not intended as a five-year project from the outset but has been extended several times in one-year increments. Consequently, a thorough revision of the technological platform is necessary. There have been numerous adjustments and modifications during the pilot period, but technological developments and knowledge gained through use over the past five years should be put together for a more comprehensive update.

Teaching in VMS

The VMS teachers are recruited from upper secondary schools, where they teach the mathematics course offered to the VMS students (the most theoretical strand of mathematics offered in the 1st year of upper secondary). The teachers are not directly employed by the project but have a third of their work hours allocated to the VMS. The VMS project enters into agreements with the schools where the teachers are employed, not the teachers themselves. These agreements include compensation for salaries to the teachers. The teachers also use their employers' equipment, with the exception of the digital drawing tablet provided by VMS. In addition to these teachers, one person with a background as a mathematics teacher is given the role of subject coordinator and is employed full-time, directly by the VMS project. The subject coordinator is responsible for coaching the teachers, selecting, developing and maintaining digital learning materials as well as more administrative tasks.

Teaching in a distributed, Internet-based environment, and more specifically in the VMS, is obviously different from teaching in a physical classroom. Being a good teacher, then, is not in itself enough to become a good VMS teacher. The VMS projects organises a one-day workshop before each school year, where all the teachers meet physically and share ideas and experiences. Teachers new to VMS meet one day before to receive extra training in use of the technology, being introduced to the didactics of a flipped classroom and teaching in the virtual classroom. The subject coordinator offers guidance and advice for the teachers throughout the school years, and there are also arenas in place where the teachers exchange thoughts on challenges and offer advice and mutual support. Teacher training and support is regarded as of vital importance for the success of the virtual school. Being a VMS teacher is both challenging and rewarding. Almost all of the 2016–17 teachers expressed that they were glad to have joined VMS (Sjaastad et al., 2017). They found it both demanding and instructive, and appreciated the professional development entailed in this form of teaching. Eighty percent stated that they would like to continue being VMS teachers, and all respondents expressed satisfaction with the quality of their education.

The Way Forward

The VMS pilot project concludes after the 2017/18 school year, but the opportunity for forced-paced mathematics education for high-performing students in 10th grade will continue. The responsibility for operating the Virtual Mathematics School is transferred from the Directorate for Education and Training to Vestfold County, one of the county administrations participating in the pilot. The technological platform and educational content is still provided by the directorate, and the administrative routines, pedagogical approach and overall model persist in this new arrangement. The provision of VMS is not yet permanent, but subject to a one-year agreement and includes economic compensation from the directorate to Vestfold County. A permanent organisational and economically sustainable model for VMS is still under development, but the fundamental framework is in place and a substantial number of issues have been resolved during the pilot project.

In addition to establishing an opportunity to study mathematics adapted to individual needs, the VMS pilot project also served as a 'proof of concept', with the potential of solving similar challenges within other disciplines. The concept and the technology from the pilot has been used to establish a service for bilingual education for students recently arrived in Norway. The Education Act grants minority language students who do not have sufficient mastery of the Norwegian language the right to bilingual teaching, but not all municipalities are able to provide such a service. In an effort to address this, a pilot project called 'flexible education[2]' has been established as a collaboration between the VMS project and The National Centre of Multicultural Education. The centre's nationwide operation focuses on work for adaptive and good education for children who speak minority languages, as well as youth and adults and to develop inclusive multicultural learning environments. The project is not intended as a replacement for bilingual teachers but is offered as an opportunity to schools that have not managed to get bilingual teachers in Arabic, Somali or Tigrinya. The disciplines covered in the flexible education pilot are natural science and mathematics, with the learning materials for mathematics brought in from the VMS pilot. The Moodle platform is used for providing the learning resources for both disciplines, organised in a similar manner as in VMS but with the added functionality of integrated quick dictionary look-ups. The solution for real-time collaboration, based on Adobe Connect, is also the same as that used in VMS. But the flipped classroom is less pronounced in the flexible education project and a more traditional pedagogical approach is employed. The project has demonstrated that technology, organisation, ways of working and the experiences gained from the VMS project are transferable to other situations where small and geographically dispersed student groups are the target group. This kind of technology-supported education contributes to the provision of equivalent education in various areas.

The Norwegian Ministry of Education and Research and the Directorate for Education and Training are currently in dialogue on establishing the VMS model as a shared service for the education sector. In a manner similar to the approach in the flexible education project, the idea is to utilise the technological platform as well as established ways of working and organisation of the venture. It will, however, be important to establish guidelines regulating the use of such a shared service. It is not desirable that Internet-based education should be a means for school owners to compromise on quality in order to reduce expenses, but rather that the service should enable the provision of education that otherwise would not be feasible. The shared national service is intended to provide optional education, as a supplement to the regular education. Typical areas of application for a new service would be as a compensatory measure for temporary needs for qualified or specialised teacher competency, or as a way to address challenges related to geography, such as providing narrow subjects in small communities.

[2] *https://youtu.be/u9H0TvvmLb4*

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THE NETHERLANDS

Authors

Dr. Jos Tolboom

Dr. Jos Tolboom is affiliated with SLO, the Netherlands Institute for Curriculum Development, where he works as a mathematics and informatics curriculum developer for upper secondary education. His research interests focus on curricular and didactical aspects of STEM education, with an emphasis on the utilization of technology for mathematics and informatics education.

Dr. Michiel Doorman

Dr. Michiel Doorman is affiliated at the Freudenthal Institute of Utrecht University. His interests are context-based mathematics education, coherency in STEM education, and inquiry and modelling as learning facilitators. He has been involved in various national and international projects on designing educational materials and connecting science and mathematics, with a special focus on context-based tasks and inquiry-based learning.

Abstract

On the 22nd and 23rd November 2016, experts of European STEM curriculum gathered to discuss the question 'What is the position of mathematics education and of informatics education in a coherent STEM curriculum?' Nine different national perspectives were sketched in papers. These papers were used as input for international discussion groups, which each developed a poster, summarizing their findings. As a way of recapitulating all of the input and the discussions, all of the participating experts completed a survey that summarized the main findings in two propositions, to be agreed or disagreed with. This chapter presents these results and draws curriculum-related conclusions upon them regarding students' STEM skills.

The consequences of including computer-based mathematics and informatics in the STEM curriculum; results from the CIDREE STEM expert meeting 2016

Introduction

In the increasingly interconnected and technology-driven world of the 21st century students will need to develop creative and flexible minds and a lifelong interest in learning (Trilling & Fadel, 2009). Digital technologies have an increasingly significant impact on education, and are beginning to change where and how people learn (Voogt, Knezek, & Pareja Roblin, 2015). Science, technology, engineering and mathematics (STEM) education has a vital role to play in this new information age in developing creativity, flexibility and interest (National-Research-Council, 2011). Recent experiences with inquiry-based learning (Minner, Levy, & Century, 2010), interdisciplinary teaching (Lafer, 1996), and computer-based mathematics) have shown the potential of these approaches to innovate STEM education in this new era. This creates the need for a better understanding of current experiences with such innovations and, in particular, with the implications for the position of mathematics and informatics in a coherent STEM curriculum. This need resulted in the organization of a CIDREE STEM Expert meeting.

The aim of the CIDREE meeting, as determined during the previous 2015 meeting, was to create an international overview of innovations in mathematics education and informatics education, the curricular chances they offer each other mutually and the coherence from the STEM perspective. Specifically, we tried to determine the key conditions to be met in order to design a curriculum in which mathematics and informatics can mutually benefit from each other's perspective, so students can experience their coherence.

We met with our science education CIDREE colleagues at the same time, in order to optimize opportunities for coherence. Thus, we requested participating countries to send two representatives: one with primary expertise in mathematics education, one with a primary expertise in science education. At this event, it was not possible for a specialist in informatics education from each country to join us, but this is an objective for following events.

The main point of discussion was the role of computer-based mathematics (CBM) in the curriculum. To what extent should which traditional mathematical skills be included in a mathematics curriculum containing CBM? How does this change the relationship with other subjects in STEM?

We also wanted to discuss whether informatics (computer science, computing science) should be included in the STEM domain. In addition, if so, what is the relation to the mathematics curriculum, as part of the STEM domain? Could the inclusion of informatics in STEM change the curriculum and didactics of the other topics? The most ambitious objective was perhaps to create guidelines for optimal coherence in the STEM-education domain, including informatics. In short, the aims of the conference were threefold:

1. *Create more coherence in the STEM-education domain as a whole*
2. *Create a mathematics curriculum with a substantial CBM-component*
3. *Create an informatics curriculum as part of the STEM-curriculum.*

Theoretical and conceptual framework

Considering the nature of informatics, one could state that this discipline was born from the marriage between mathematics, from the software perspective (Turing, 1936), and electrical engineering, from the hardware perspective (Burks, Goldstine, & Von Neumann, 1946). How is this dichotomy reflected in the Dutch secondary education curriculum?

The topic of hardware can usually be found in the informatics part of the STEM curriculum. For instance, in the Dutch informatics curriculum for upper secondary education, one of the five obligatory domains is domain E Architecture and three of the twelve elective domains are domain K Computer architecture, domain L Networks and domain N Physical computing (Barendsen, Grgurina, & Tolboom, 2016; Barendsen & Tolboom, 2016). In the physics curriculum there is some focus on hardware. For pre-university education, subdomain D1 ‘Electrical systems’ contains the classic calculation and construction of circuits with resistors, lights etc. For senior secondary education, there is the subdomain G1 Use of electricity, in which the candidate should be able to describe and analyse generation, transport and applications of electricity based on physical concepts. Apart from that, in senior secondary education, there is also an optional subdomain G2 Technical automation, containing the construction of measurement, control and control systems.

Software, as regarded from the active, programming side, is a classical domain of informatics and thus widely spread in curricula all over the world (Sahami et al., 2013). In secondary school informatics curricula there is an international trend to pay attention to fundamental aspects of informatics, or ‘the mathematics in informatics’ to put it differently. Unfortunately, in The Netherlands and many other countries, informatics is not an obligatory part of the curriculum. Mathematics, of course, is obligatory in almost all secondary curricula worldwide, but where in mathematics curricula is this worldwide application of algorithms visible?

When trying to develop a coherent STEM curriculum including mathematics and informatics, it seems worth taking these old bonds as departure points. Specifically considering the relation between mathematics and informatics, their interwovenness is formulated by Gravemeijer at al. (2017, p. 2) as follows:

Although we recognize, as do others, that mathematics education for the future should be considered within the context of STEM-education (English, 2015), in our view, mathematics deserves focused attention. This is especially true because of the way computerization affects mathematics and vice versa.

To understand the interwovenness between mathematics and informatics more precisely, we raised the questions: what is the influence of mathematics on informatics? And the other way around: what is the influence of informatics on mathematics?

These questions are to be answered within a framework of the general research question: What are the design principles for a coherent mathematics and informatics curriculum?

In the Dutch mathematics curriculum, mathematical thinking (cTWO, 2007) was chosen as a departure point for the formulation of the actual domains. From the six formulated specifications, Drijvers (Drijvers, 2015a, 2015b) focused on these three: abstracting, modelling and problem solving.

Method

In order to establish a common ground for future developments, we followed an iterative process. First, participating stakeholders sent us a position statement with respect to the conference theme.

These preliminary papers - of which the final versions are included in these proceedings - from the contributing countries, were presented and submitted to a plenary discussion. In Table 1, the titles of the papers and presentations are presented.

↓ ***Table 1:*** *The starting input of the conference*

Country	Name of presenter(s)	Title of contributions
Belgium, Flanders	Patricia DeGrande, Lotte Milbou	Mathematics and STEM in Flanders
England	Adrian Smith, Alec Titterton	Let's fix maths education
England	Miles Berry, Andrew Csizmadia	The silent C in STEM
Estonia	Ülle Kikas, Terje Hõim	Changing mathematics education in Estonia: Computer-based statistics project
France	Gilles Aldon, Sophie Soury-Lavergne	The new French Curriculum for mathematics and technology
Hungary	Csaba Csapodi	The remaining velocity problem with different solutions: A Case Study
International baccalaureate	Deborah Sutch	Development of a STEM course within the IB Diploma Programme
Ireland	Rachel Linney, Anna Walshe	Curriculum reform of applied mathematics in Ireland
The Netherlands	Wouter van Joolingen	Drawing-based modelling to support higher order thinking in mathematics and science (presentation, no paper)
The Netherlands	Nataša Grgurina	Modelling as a New Literacy
Norway	Ellen Marie Bech	Pilot project - Computer programming in lower secondary school
Slovenia	Radovan Krajnc, Mojca Suban	Present status of informatics and its presence/ inclusion as an auxiliary tool for learning mathematic in Slovenia
Sweden	Olof Andersson, Helena Karis	Digital competence in Swedish curriculum

After these presentations, the participants were placed in small, heterogeneous (i.e. internationally mixed) groups with the assignment to identify core themes in the body of presentations. Their findings were communicated through a poster. Each group presented their poster the next day.

The analysis of the posters helped us condense the results into fundamental questions and determine the need for a follow up, as well as and which the curricular elements a follow up should contain.

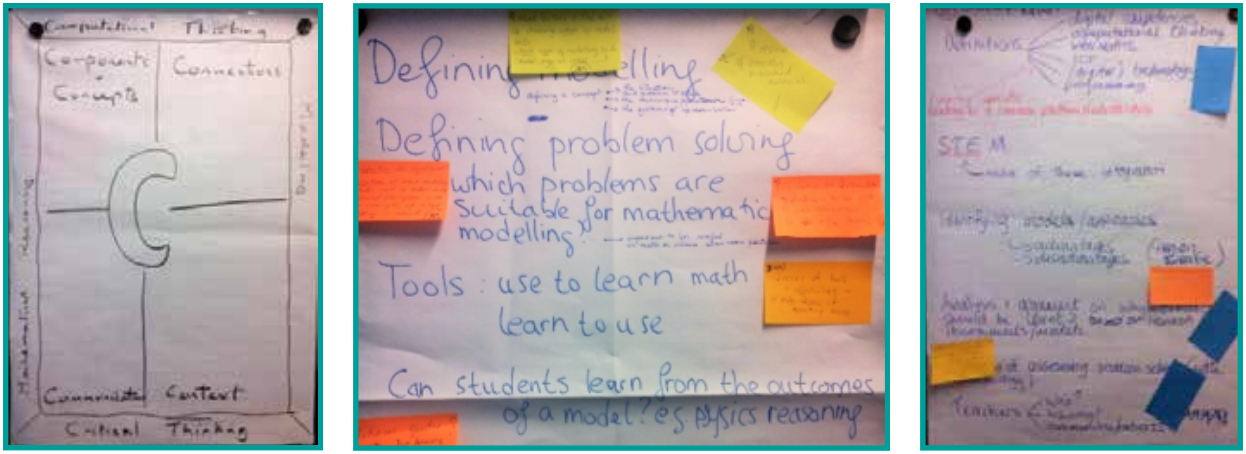
Next, we decided to condense the concluding survey among the participants to three curricular propositions. Participants were answered to react with a ‘yes’ or ‘no’, in order for us (or for the expert group or for CIDREE) to be able to make a clear decision whether or not to pursue the proposed direction. Besides a simple 'yes' or 'no', participants were asked to motivate their answer.

Finally, participants compiled a final version of their paper, in which they were able to process their experiences from the meeting. The resulting papers can be found at ***http://rekenenwiskunde.slo.nl/***.

Results

The posters of the groups highlighted core themes and issues that needed further discussion within the CIDREE consortium. The variety in content and layout of the posters made it difficult to aggregate the main ideas. For that reason, we summarized each poster respectively.

- *The first poster tried to capture the relationship between modelling, computational thinking and mathematical reasoning. Their drawing attempting to bring these perspectives together in one model.*
- *The second poster emphasized the importance of computer science without computers and highlighted the need for a better understanding of what progression looks like in informatics education and to what extent that parallels progression in mathematics education. As an example, they suggested to become more explicit about problem solving techniques in the mathematics curriculum and to connect this with problems in (functional) programming.*
- *The third poster addressed modelling, the need for good definitions of modelling and problem-solving competencies, and the position of (computer) tools in education. A central question on the poster is: Can students learn (e.g. physical reasoning) from the outcomes of a (computer) model?*
- *The fourth poster also highlighted the need for clear definitions and a consensus on terminology and vocabulary (programming, coding, computational skills, informatics, algorithms, problem solving, modelling, simulating, technology, computer science, …). In addition, it asked for a better understanding of didactics of programming in relation with STEM education. Finally, they pleaded for the inclusion of Arts as a creative discipline in the discussion: from STEM towards STEAM.*
- *The fifth poster also addressed the need for definitions and a joint platform. Furthermore, this poster added the issue of assessment to the discussion. Can we assess progress in problem solving skills (with technology)? This poster also highlighted another issue of implementation related to the needed professional development of teachers (who, how, learning communities?).*



↑ ***Figure 1:*** *posters 1, 3 and 5.*

Below, we present the results of the three evaluative questions that were sent to the participants after the meeting.

1. *Do you agree that a conclusion of the conference is that modelling is a key student skill for success in a coherent STEM curriculum, when informatics (computer science) is included in STEM and mathematics has a substantial computer-based component?*

These were the respondents' answers:

Yes	**18**	94,7%
No	**1**	5,3%

This indicates that respondents significantly[1] consider modelling to be a key student skill, when informatics is included in STEM, while mathematics has a substantial computer-based component.

[1] $p=0{,}00000191<0{,}05$

Explain briefly why you consider modelling as a key student skill. Below, the remarks from the participants that expand on their answer:

- *Yes and no - algorithm are also a fundamental part, also a clear definition of modelling is needed - modelling for applying or discovering?*
- *We need to agree on a definition on some key concepts (incl. modelling, digital competence/computational thinking/CS)*
- *The 'Yes' is for a slightly different version of the conclusion, where 'when' is replaced by 'where'.*
- *Yes, but for a slightly modified statement, with 'when' replaced by 'where'. Modelling is a key skill as mathematics is essentially [used as] a modelling tool for quantitative phenomena and informatics enables one to implement/algorithmize such modelling.*
- *Through the process of modelling, a student can show his or her deep understanding and can use his or her knowledge.*

- *Through simulation, students can ask the 'What if...' question and explore by manipulating system parameters or altering the data principally, I agree. However, the examples of modelling given in the conference were not the best ones to start propagating modelling in school curriculum.*

- *I'm not sure to be able to answer by yes or no to that question. Yes, modelling is a key student skill but not only when informatics is included. Yes, mathematics has a substantial computer based component as well as informatics has a strong mathematical component.*

- *This is exactly what emerged from the discourse after and the presentations themselves. Maybe modelling is not an explicit student skill, but it must be the foundation of the mathematics practices and the learning situations organized by teachers*

- *Mathematics includes algorithmic thinking. We cannot imagine one without the other. During the meeting it was not always clear what was meant by 'modeling'. We also speak of our ten-based number system as a model to represent quantities, the numbers of axis as a model to represent the numbers, ... Computer modeling is also involved in the further learning trajectory. This was focused on, but that was less clear to me at the beginning. Do those computer models have the same place as the other models? Are these models also explained (how do they work?), can the pupils also make models themselves (and thus program them?) Only then will it be interesting, otherwise they are only 'tools such as a calculation device'. I thought that was also the case on the last day. Perhaps it might also be interesting to see which models exist to support or explain better some mathematical concepts. The presentations of the various countries also dealt with how ICT or computational thinking were included in the curricula, but how this was integrated into mathematics was much less addressed. The skill to work with models is obviously related to mathematics. Mathematics is full of models, without models there is no mathematics. The less classic models can also be used, such as computer models.*

- *Modelling has an important role in all problem solving in everyday life. Applying our subjects is also a part of this.*

We conclude that, in this context, there is still a need for some clarification on terminology. Nevertheless, modelling seems to be at the heart of mathematics education when informatics is introduced into it through computer-based mathematics.

2. *Do you agree that a conclusion of the conference is that computational thinking is a key student skill for success in a coherent STEM curriculum, when informatics (computer science) is included in STEM and mathematics has a substantial computer-based component?*

Yes	**18**	90%
No	**2**	10%

We conclude that the respondents significantly[2] consider computational thinking to be a key student skill for success in a coherent STEM curriculum, when informatics (computer science) is included in STEM and mathematics has a substantial computer-based component

[2] $p=0{,}00002003<0{,}05$

Explain briefly why you consider computational thinking (CT) as a key student skill. Below, the remarks from the participants that expand on their answer:

- *The computer-based component of the mathematics does not have to have a coding element though, it can be use of technology without programming.*
- *We need to agree on a definition on some key concepts (incl. modelling, digital competence, computational thinking, computer science)*
- *The definition of computational thinking is still not well-defined for me*
- *But identifying what is really meant by computational thinking is crucial and should come first, what is meant by unplugged computational thinking, identifying the development of this and into digital technologies*
- *As touched on above, computational thinking enables one to operationalise modelling. It is important to deal with real-life problems.*
- *At the heart of both mathematics and computer science is problem-solving and computational thinking helps students develop problem-solving skills*
- *See the 21th century skills.*
- *Computational thinking is both part of mathematical thinking and computer science; in order to understand the world of the XXI-st century, students have to build for themselves a basis of informatics culture, and to understand how computers work.*
- *I do believe this, but I also think that mathematics about the mathematics is important to. So modelling and computational thinking are important components, but it is not the only thing.*
- *It seems evident -almost by definition- that computational thinking is need when utilizing the ict-tools available. And that some programming skills will be need in tuning these tools.*
- *Currently, I do not know exactly what is computational thinking. What difference with reasoning, calculating, applying an algorithm or creating an algorithm? During the conference, we talk about computational thinking but we didn't define it. It remained implicit.*
- *Thinking in the same way as how a computer works (working with a text editor, spreadsheet) is very useful, not just for sciences, engineering or mathematics. It is also algorithmic thinking for these subjects (starting with the algorithm of digitizing for example) to transforming in steps what the robot has to do.*
- *I'm not sure yet what I think computational thinking exactly is and whether it is a key skill or not.*

We conclude that there is still some discussion needed in order to reach terminological consensus about computational thinking, the intuition of the experts seems to indicate CT is key to STEM.

3. Are you at forehand interested in conducting a curriculum experiment in your home country with respect to modelling and computational thinking, in the context of a STEM curriculum, informatics included and mathematics having a substantial computer-based component?

Yes	**18**	90%
No	**2**	10%

We conclude that member countries are significantly[3] interested in a curriculum experiment regarding modelling and computational thinking.

Conclusion

As a result of this two-day expert meeting, we conclude that the attendants consider both modelling as well as computational thinking to be key student skills for success in a coherent STEM curriculum, when informatics (computer science) is included in STEM and mathematics has a substantial computer-based component. However, a shared precondition is to create consensus on what we mean by concepts like modelling and computational thinking. When returning to the initial questions:

What are the influences of mathematics and informatics education on each other in our increasing technology driven society?

Informatics meets mathematics as both disciplines include modelling, algorithmic thinking and problem solving. In addition, the two disciplines meet when considering the 21st century skills such as creative and critical thinking and the extensive list of digital skills. However, both informatics and mathematics also have an existing right on their own.

What are the design principles for a coherent mathematics and informatics curriculum?

Modelling and the use of simulations seem to be important levers for the mathematics and informatics curriculum. Through the process of modelling, students need to use their knowledge, and can develop and show their understanding of real-world situations. Through simulations, students are invited and motivated to ask 'What if...' questions. Computer simulations enable explorations by offering tools to manipulate system parameters or to alter data and to systematically investigate the consequences of these manipulations.

These results show that within the CIDREE consortium we need to better understand what these computational skills are and how progress in student learning with respect to this can be supported and monitored. The CIDREE yearbook 2018 and future expert meetings will contribute to this shared understanding. Experiments in the near future are necessary and participants of the meeting are willing to continue working on them in their home countries.

[3] *$p=0,00002003<0,05$*

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et technologiques

eduPôle Walferdange
28, route de Diekirch
L-7220 Walferdange
Tél. : 247-85187
Fax : 247-83137
secretariat@script.lu

SCRIPT, Walferdange novembre 2018

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