STEM education in Flanders : literacy and a positive attitude towards STEM

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STEM education in Flanders:

How STEM@school aims to foster STEM literacy and a positive attitude towards STEM

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INTRODUCTION

The need for STEM professionals

We are increasingly exposed to complex societal and technological problems. Qualified *Science*, *Technology*, *Engineering* and *Mathematics* (STEM) professionals are needed to solve these problems and cope with contemporary demands such as sustainable energy and efficient healthcare (Bøe et. al, 2011). It is not surprising then that the World Economic Forum's *Future of Jobs Report* (2016) predicted a job gain in STEM fields for the following years. However, we do not only need STEM professionals who can solve these problems. We also need people with a basic understanding of STEM. All citizens, even non-STEM professionals, should have the skills and competences necessary to deal with the challenges of our information-based and highly technological society (National Society of Professional Engineers, 2013). STEM-literacy, i.e. the awareness of the nature of science, technology, engineering, and mathematics, and the familiarity with fundamental concepts from each discipline, should be an educational priority for all students (Bybee, 2010; National Academy of Engineering and National Research Council, 2014).

STEM literacy and attitudes

International achievement studies provide insight into current and past students' literacy level and attitudes towards STEM, in particular in the field of science and mathematics. Taking into account the increasing need for STEM professionals and STEM literacy, it is encouraging to read that there are more countries where the science and mathematics performance level of students increased than countries where the performance level decreased between 1995 and 2015 (Martin, Mullis, & Loveless, 2016). Also the percentage of students liking science appears to have increased in more than half of the participating countries (Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly 1997a; 1997b; Martin, Mullis, Foy, & Hooper, 2016; Mullis, Martin, Foy, & Hooper, 2016). However, for mathematics, the results remain mixed (Martin, Mullis, & Loveless, 2016; Martin et al., 2016; Mullis, et al., 2016). Moreover, students' positive attitudes towards science and mathematics appear to decrease with age. The percentage of students liking science and mathematics (a lot) declines between the 4th and 8th grade (Martin et al., 2016; Mullis, et al., 2016). Therefore, schools need to be encouraged to stop this decline and to avoid that less and less students end up in STEM fields when they grow older.

The leaking STEM pipeline

In Anglo-Saxon countries the metaphor of a pipeline is often used to describe a declining interest in STEM fields with age. The STEM pipeline describes a career trajectory in STEM fields from secondary education to the labor market. The entrance of students into this pipeline in secondary education by encouraging them to choose STEM subjects at an advanced level is often considered a major challenge. However, the entrance of students into the STEM pipeline is not the only challenge. During every transition period in the educational and professional career the STEM pipeline appears to leak. Retention problems in STEM fields and leaks in the STEM pipeline are considered equally problematic. Moreover, flawed flows of students throughout the STEM pipeline are said to cause underrepresentation of women, minority and other socially disadvantaged students in STEM fields (Knipprath, 2017). It comes as no surprise then that policymakers, the industry and educators are seeking ways to motivate students to choose a STEM field during their educational and professional career.

The STEM pipeline in Flanders

In Flanders, the STEM pipeline appears to leak the most during the transition from secondary to higher education. At the secondary education level, STEM fields or STEM oriented study programs are frequently chosen in Flanders. Forty one percent of the students in secondary education successfully complete a study program with a substantial amount of science, mathematics and/or technology curriculum contents (Van den Berghe & De Martelaere, 2012). In fact, the study program *Science and Mathematics* is the most popular study program, and relatively many girls choose this study program (Van den Berghe & De Martelaere, 2012; VVKSO, 2012). However, when both girls and boys grow up and enter higher education, interest in STEM fields declines sharply. This declining interest in STEM near the end of secondary education indicates that rousing young children's appetite for STEM at an early age is not sufficient. Solutions need also to be sought at the secondary educational level.

STEM@school

Many initiatives have been taken the last five to ten years in Flanders to increase the interest of children and adolescents in STEM. STEM academies providing extra-curricular activities with a focus on technology have been established, and many schools began to offer small-scale STEM projects. However, until recently, guidelines to develop learning materials for well-defined and sustainable STEM projects were lacking. In addition, STEM projects mainly targeted students in elementary schools and the first two grades in secondary education (grade 7 and grade 8) with a focus on technology, undervaluing the need to integrate technology with other STEM disciplines. Therefore, we started with our project, called STEM@School, to develop research-based learning materials for large and sustainable integrated STEM projects in secondary education from the 9th grade on. The main goals of our STEM@school project, funded by the Flemish Government, are to increase STEM literacy and to show students the relevance of STEM for everyone's life.

INTEGRATED STEM EDUCATION

The principles of integrated STEM

The main principle of our learning materials is integration of the various STEM disciplines. The idea of integrated STEM education originates from the awareness that the nature of the daily practices of most STEM professionals blurs the lines between science, technology, engineering and mathematics (Wang, Moore, Roerhig & Park, 2011). Real world problems are not fragmented in isolated disciplines as they are taught in schools, and in many cases people need skills that cut across the disciplines (Beane, 1995; Czerniak, Weber, Sandmann, & Ahern, 1999). Integrated STEM education aims to remove the barriers between the four disciplines (Wang, et al., 2011) and encourages students to understand the relevance of STEM to solve various technical and social problems in real life. However, the concept of integrated STEM education is complex and challenging, as integration of subjects is more than parallel treatment of different subject areas. More specifically, integrated STEM education designates an instructional approach in which students participate in engineering design and/or research and experience meaningful learning through integration and application of science, technology, engineering and mathematics (Moore

& Smith, 2014). Therefore, we developed learning materials and an instructional approach for integrated STEM within the theory of social constructivism, inspired by existing frameworks for integrated STEM education (Bryan, Moore, Johnson & Roehrig, 2015; Kelley & Knowles, 2016). From these settings, in total five principles were extracted: (1) integration between STEM disciplines, (2) problem-centered learning, (3) cooperative learning, (4) inquiry-based learning and (5) design-based learning. The key principles were translated into learning materials for eight learning modules for secondary school students.

The development of learning modules in teacher design teams

STEM@school is a collaborative project of the University of Leuven, the University of Antwerp and two educational umbrella organisations, supporting approximately 70% of the population of secondary schools in Flanders: Catholic Education Flanders and the GO!. The educational umbrella organisations encouraged schools and teachers to cooperate and to develop learning modules together with researchers in teacher design teams. Teachers from up to ten schools, two pedagogical counselors from the two largest educational umbrella organizations in Flanders, and up to six researchers worked together throughout the project to develop integrated STEM learning materials. During the first year of the project, the members of each teacher design team met on a very regular basis, at least once a month. From the second year of the project, thirty schools used the learning materials and researchers studied the effectiveness of the materials. During the implementation process, teachers, pedagogical counselors and researchers gathered regularly to discuss the application of the learning materials in the classroom and to learn from each other's experiences. During these sessions, teachers gave input to improve the learning modules. Throughout the project, it was noticed that the teachers increased their expertise and required less guidance. Teachers developed collaboration and negotiation skills, since they had to exchange ideas and make compromises in order to create fully-integrated and classroom-appropriate learning materials. It was a major challenge for both teachers and researchers during the process to find a way to match the different curriculum guidelines from various STEM subjects, such as mathematics, physics and engineering, to enable integrated learning.

The eight learning modules require teaching time that amounts to 9 to 12 weeks, 4 to 5 hours a week. Most often, a separate subject, an integrated STEM subject, was introduced into the curriculum to implement the materials. Besides this integrated STEM subject, students still take traditional STEM subjects such as physics and mathematics, but these STEM subjects were to be aligned with the curriculum of the integrated STEM subject.

Schools offer two to three learning modules to their students per school year. The modules consist of fascinating challenges. One of the learning modules addresses the challenge for the students to build a model of a passive house with a sun boiler, in which the hot water of the sun boiler flows through the floor heating system. The temperature of the house is controlled by an on/off control system. Another example is the Green Wave module. In this module, students are challenged to design and build a model of a car that can autonomously drive through a predefined green wave. Students are presented with the situation depicted in Figure 1, which they first have to rescale to a smaller format. They are challenged to let their car reach the finish line as quickly as possible, without having to stop for any yellow or red lights and without exceeding the speed limit. The Green Wave module starts with the building of the autonomous car model. To do so, students first need to design the layout of the car and choose suitable drive mechanisms and electronics. Once the car is built, the green wave mechanism needs to be explored. In doing so, students discover that they need knowledge about the concepts of position, velocity and acceleration and about the relationship between these concepts and how to translate them into instructions to control the car. Over the course of this module, students identify particular learning needs; develop mathematical models of the relationships between position, velocity and acceleration; and program, test, and refine their autonomous cars in order to solve the challenge.

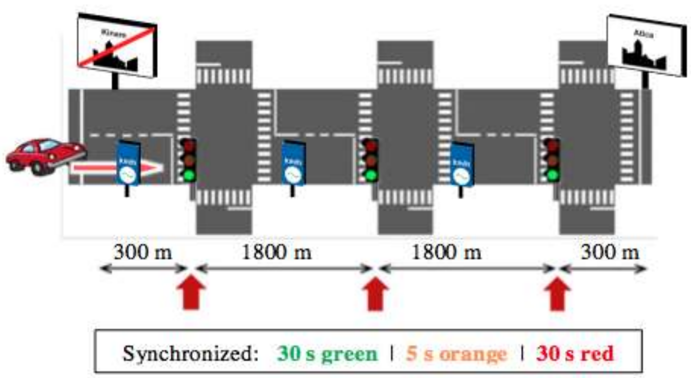

FIGURE 1 The challenge of the *Green Wave* learning module: Build and program a car so that it can pass three synchronized traffic lights when they are lit green, on a scale model of the depicted situation

Other learning modules challenge students to develop a security system, to design a computer program in order to analyse real astronomical data and to describe the motion of a binary star, to design an application of growing algae, a passive house or a rehabilitation device. With these different challenges, we also intended to address the different needs according to gender. Sjøberg and Schreiner (2010) showed that it is for girls more important than for boys to indicate the social relevance of STEM in order to convince them to choose STEM fields. Therefore, challenges should not be chosen only from typical STEM application domains like space exploration or race cars. Also environmental care and biomedical topics, female students are mostly interested in (cf. Sjøberg& Schreiner, 2010), should be incorporated.

RESEARCH

The development of our learning modules is based on design research. When developing the new instructional approach and learning materials we took into account the research results from discipline-specific educational research, for example about misconceptions in physics. But we also studied the impact of our modules, after being developed and implemented in the classroom. Overall, we focus on the effectiveness of the learning materials for integrated STEM education and on how teachers and schools can positively influence the implementation of integrated STEM. In order to measure effectiveness, various measurement instruments have been developed. We measured effectiveness in terms of STEM literacy (i.e. mathematics, physics, technology, research and design skills, the ability to apply integrated STEM knowledge) and STEM attitudes (among teachers and students). In addition, we videotaped classrooms to observe the implementation of integrated STEM education and interviewed students and teachers. We performed our study in both experimental and comparison groups. Comparison groups were schools who did no adopt our learning modules. In addition, we investigated how teachers can continue to design successfully and autonomously integrated STEM projects, even when our project will no longer be funded.

Many data need still to be analyzed, but the results of the first implementation year revealed that students who followed the integrated STEM subject scored higher on test items regarding the application of mathematical concepts and on integrated STEM items than students who followed the traditional (separate) STEM subjects in the comparison group. Our study also revealed that an integrated approach towards STEM positively affects students' collective engagement. Furthermore, students in the experimental condition reported more positive attitudes towards STEM than those in the control group, even after controlling for other characteristics. Students in the experimental schools were more interested in science and technology. However, they also indicated that they perceived mathematics as more difficult than the students in the control schools. A possible explanation could be that students have a more realistic view on mathematics when STEM is taught in an integrated way (De Loof, Struyf, Boeve-de Pauw & van Petegem, 2017).

Teachers play an important role in the implementation of educational changes and new instructional practices. Structural equation models showed that teachers' attitudes are positively linked with their instructional practices. Moreover, different aspects of school context influence instructional practices either directly or indirectly via teachers' attitudes (Thibaut, Knipprath, Dehaene & Depaepe, 2018). Similar results were found through qualitative data. Teachers indicated that teacher and school context characteristics are necessary for successful implementation such as perseverance, flexibility, a willingness to coach during problem-centered learning and a constructive attitude to deal with failure and a multidisciplinary, goal-oriented team.

Since integrated STEM education has been an underdeveloped research field so far, we believe our research contributes to the scientific research literature. Based on our research, we are also able to address the needs of practitioners and policy makers by developing an instructional approach and learning materials for integrated STEM education and making recommendations to guarantee a successful implementation of this approach. The quality standards proposed by the Ministry of Education to Flemish schools in 2017 for integrated STEM were largely inspired by our research project. Subsequently, we received in 2017 the Best Research and Practice Project Award of EAPRIL, recognizing the substantial impact of our project in the research field as well as in the field of education.

FUTURE

Our project is coming near its end. Learning modules have been developed and are now offered for free after registration at our website, www.stematschool.be. Besides learning materials, we offer an inventory of materials teachers will need and schedules to organize integrated STEM education throughout the school year. In addition, we offer advice for teachers to evaluate the learning progress of their students. Until now, the learning modules were only available in Dutch. But in the near future the materials will be translated with support of the European project *Scientix* and will be downloadable on their website, http://www.scientix.eu/.

Our learning modules and output will therefore be sustainable. However, we do believe that the learning materials for integrated STEM projects do not have to be implemented in their current form forever. Our current projects and learning materials can be considered an example of how the project's theory can be translated into future integrated STEM projects and learning materials. To inspire teachers to design new projects and learning materials autonomously in the future we established a teacher training course for integrated STEM (iSTEM) at the University of Leuven. Student teachers in the science, mathematics and engineering departments can choose an elective course on instructional approaches for iSTEM. After a theoretical introduction to iSTEM, we familiarize our student teachers with the design methods we developed in STEM@school. Based on our experiences in STEM@school we developed a tool for designing learning materials for iSTEM, called *CODEM for iSTEM* (De Meester, Langie, De Cock & Dehaene, 2017). The guiding principle of this tool is that development and implementation of learning materials will be more successful when they are the result of co-creation in teacher design teams. Once the student teachers are introduced to iSTEM and the design methods, they are grouped in teacher design teams. Each team defines learning goals and chooses a related challenge in order to develop learning materials. Learning goals must be related to integrated STEM, but also to a specific STEM discipline they will have to teach. If possible, we ask them to test out their own developed materials in a real classroom as part of their preservice training. To our knowledge, we are the first university incorporating iSTEM in our teacher training programs. At the moment *Instructional approaches for iSTEM* is still an elective subject. When iSTEM becomes well-established in secondary education and within the reformed teacher training program, we will make this course mandatory in all teacher training programs for science and technology. We sincerely hope that the Flemish government will continue to support research about integrated STEM education and that integrated STEM education will become a well-established practice. Although our project is near its end, this is only the beginning of a bright future for integrated STEM education that may successfully addresses todays' technological and global challenges.

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