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► To cite this version:

Behiye Ubuz, Nelleke Braber, Clelia Cascella, Michelle Stephan. An introduction to TWG26: Mathematics in the context of STEM education. Thirteenth Congress of the European Society for Research in Mathematics Education (CERME13), Alfréd Rényi Institute of Mathematics; Eötvös Loránd University of Budapest, Jul 2023, Budapest, Hungary. hal-04416795

HAL Id: hal-04416795

<https://hal.science/hal-04416795>

Submitted on 25 Jan 2024

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An introduction to TWG26: Mathematics in the context of STEM education

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In TWG26, the papers and posters were grouped under four themes, that are (i) Perception/Beliefs, (ii) Student Cognition, (iii) Designing STEM Learning Environments, and (iv) STEM/STEAM Professional Development. Presentations and discussions raised questions and needs regarding the structural and systematic changes needed to support STE(A)M.

Keywords: Interdisciplinarity, mathematics, STEM, STEAM.

TWG26 met for the fourth time in Budapest, at CERME13, to continue the work started at CERME11. The scientific interest in empowering STEM teaching has increased over time, calling for more reflections about teaching protocols and designs, as indicated also by the research projects recently granted, whose results have been presented in Budapest. At CERME13, 18 papers and 7 posters were submitted. Among them, 12 papers and 5 posters were accepted and presented, involving authors from 9 different nationalities (i.e., Denmark, Germany, Italy, Netherlands, Portugal, Spain, Sweden, Turkey, and USA). The papers and posters were grouped under four themes, that are (i) *Perception/Beliefs* (2 papers + 1 poster), (ii) *Student Cognition* (5 papers + 1 poster), (iii) *Designing STEM Learning Environments* (4 papers), and (iv) *STEM/STEAM Professional Development* (1 paper + 3 posters). As usual, themes looked very intertwined and, therefore, each paper could have been assigned to multiple themes. Nonetheless, we assigned each of them to one single category looking at its core contribution, and in agreement with the authors. Most of the presented research was about the role of mathematics - both as a tool to better achieve some goals and as an aim, i.e. to boost students' learning and understanding of mathematics - in STEM. Just a few of the presented papers also include Arts (STEAM), none of them included Reading (STRE-A-M). The ideas and issues in the papers and posters will be presented under these four themes in the upcoming parts.

Perceptions and beliefs

Within this theme, two papers and one poster were presented. The first paper, by Pocalana, Bini and Robutti, explored teachers' beliefs about the role of mathematics in designing STEAM activities. These authors found that teachers' beliefs and practices can be sharply influenced by both personal and contextual factors (such as the context they work in, their professional experiences, and their background), and that, in designing STEAM activities, teachers cannot forget to "be in others' shoes" in order to change their lens, connect with colleagues teaching other subjects and find their role in an interdisciplinary environment.

The second paper, by Güzeller and Akyüz, was aimed at exploring teachers' perceptions of using Virtual Field Trips (VFTs) in STEAM teaching. Their results indicate that teachers held positive perceptions about VFTs because they provided authentic, engaging learning environments for students, that are easily accessible and do not require high costs/risks. On the other hand, teachers pointed out that VFTs are limited and thus they often struggled to find VFTs suitable to pursue specific learning outcomes.

Finally, in their study, Ferreira, Costa, Peixoto, Monteiro and Silva presented results from their Erasmus+ project which was developed with the participation of 9 European partners from four countries, including higher education institutions and elementary schools. The project was aimed at assessing, within the framework of the self-efficacy theory (Bandura, 1977, 1997), teachers' beliefs about their ability to be successful in teaching STEAM. Results showed that higher levels of teachers' self-efficacy are not always positively associated with their actual level of knowledge and that there is still room for improving disciplines' integration.

Student cognition

Within this theme, five papers and one poster were presented and focused on empirical investigations into student STEM learning at K-16 educational levels (Kindergarten through undergraduate degree). At the elementary level, Eckert designed activities to understand young children's computational reasoning in a spatial reasoning task. They assessed the students' computational thinking in relation to the concepts of sequences and loops (Brennan & Resnick, 2012) with an instrument inspired by Clarke-Midura et al. (2021) which considered kindergarten students' algorithmic thinking as a sub-section of computational thinking. This study found that there were three main orientations brought to the problems, one of which constrained students' reasoning, thus resulting in potential revisions to the instructional materials. Another study explored university level engineering students' computational thinking by analysing the physics, mathematics and coding reasoning used to program a car to run along a particular track. In their analysis of classroom observations and students' resulting projects, Costa, Martins, and Domingos found that students engaged in abstraction, decomposition, pattern identification, and algorithmic reasoning, all hallmarks of computational thinking.

Santágueda-Villanueva, Lorenzo-Valentín, Adelantado-Renau and Monferrer also studied the reasoning of primary school children, but this time during the enactment of STEAM activities that prompted students to develop both mathematics and science concepts. They designed and enacted four lessons in which students explored a variety of issues within an organic garden. Their findings indicate that students had difficulty with measuring instruments as well as engaging in proportional reasoning, suggesting revisions to the materials.

Two projects explored the reasoning of students in the middle grades. In a study with seventh grade students, Kurudirek and Arslan showed that their (co)variational reasoning levels played a significant role in interpreting scientific concepts as well as the use of construction tables and graphs as they reason quantitatively. They recommend that educators design STEM learning environments that consider (co)variational levels of students. In another study with 7th graders, Larsen and Østergaard compared two inquiry teaching approaches in STEM learning environments, the first based on the 5E (Engage, Explore, Explain, Elaborate, Evaluate) model (Bybee, 2018) and the second on the

Pedagogy of Questioning the World developed within the Anthropological Theory of the Didactic (Chevallard, 2015), to understand what type of mathematical reasoning emerges within each approach. Findings indicated that both inquiry devices had difficulty supporting students to make deep mathematical inquiries, staying at rather superficial investigations.

Kop, for his part, notes that when teachers discuss problems using mathematics in physics, they typically focus primarily on mathematical techniques (Redish & Kuo, 2015). His study investigated whether an instructional intervention that fore fronted secondary students' analysis of the *structure* and *graphing* of formulas in a mathematics class would support their reasoning with formulas in physics. Indeed, his study showed that these students drew on their mathematical reasoning with formulas in order to interpret physics formulas more successfully.

Designing STEM learning environments

Within this theme, four papers were presented. The first paper from Schönbrodtl, Hoeffler and Frank addresses the fact that the increasing relevance of the applications of Artificial Intelligence (AI) for our society results in the demand for a stronger integration of AI education into school. The researchers developed a digital learning module on the problem of human activity recognition on smartphones as an opportunity to combine knowledge from mathematics, computer science and physics in an interdisciplinary way. The paper describes four design principles for the digital learning module as well as the main modelling steps of the learning module with the connection to computer science and physics highlighted. The learning module was piloted in the context of a mathematical modelling day where nine students from grade 9 to 12 participated. As a result, students had very lively discussions and a final evaluation showing that the students had a great interest in the topic of AI.

The second paper by Stoffels highlights a project in which various stakeholders in STEM education and STEM careers from schools, universities, businesses, politics, and society work together to create a space for young people to experience self-efficacy in mathematics. This is achieved through long-term problem solving of real-life problems containing mathematics from businesses as well as contact with their employees moderated by mentors. An important element in mentoring is the self-efficacy of students as well as the mentors. The question the paper addresses is to what extent authentic long-term problem solving in the setting of authentic STEM activities offers experiences to develop self-efficacy of students but also mentors. Data show that students experience self-efficacy in the long term and gives insight in mentoring self-efficacy and what this means for teacher preparation.

In a third paper, Pugalenti, Stephan and Pugalee argue that STEM learning environments should be designed using a systems approach. Each discipline in the STEM acronym engages in discipline specific practices that are not completely aligned when crossing into the other disciplines. Rather than attempt an interdisciplinary approach where some aspect of two or more disciplines “shows up” in some way in the instruction, these authors designed an instruction instructional sequence for a 7th grade mathematics classroom that positioned students as engineers when needed and as mathematicians at other times. Designing instruction with this approach allowed students to learn the discipline-specific practices in both engineering and mathematics as well as some meta-practices such

as switching back and forth between the two expertise, developing ethical thinking and learning to communicate either mathematically or as an engineer.

Finally, Ubuz and Aydinyer also explored 7th grade students' reasoning about the engineering design process through implementing a Project Based Learning (PBL). In this study, they distinguish three types of cognitive styles students may engage in: field-dependent, field-mixed and field-independent cognitive styles. Students used the engineering design processes while designing a two-dimensional scale plan of a neighbourhood. To understand the engagement of the three cognitive styles students with the engineering design process, verbal protocols throughout classroom observations and interviews were collected from 97 seventh-grade students. The results show that the structured PBL environment seemed to accommodate the needs of students with different cognitive styles because of contextualizing, visualizing, and collaborating opportunities in this environment. Field-mixed and field-independent students were better than field-dependent students in developing different strategies to help them continue the project and in reconsidering previously made decisions, if needed.

STEM/STEAM professional development

Within this theme, one paper and three posters were presented. The paper by Yabaş, Ceyhan, Doganca-Kucuk and Corlu focused on how mathematics teachers who have completed a year-long STEM Leader Teacher Professional Development (PD) Program integrate social and cognitive dimensions into their implemented STEM lesson plans. Data collected for the PD program which lasted 92 hours included digitally recorded workshops, online theoretical and practical lessons, and interactive tasks. The lesson plans were evaluated under four categories: the originality of the authentic context, flexibility of the problem for alternative solutions, integration of cognitive and social aspects, and interdisciplinarity. The results showed that most teachers integrated cognitive and social dimensions and provided flexibility in solutions. However, teachers struggled to integrate an original context into the problems.

The poster presented by Svendsen is an ongoing PhD study that aims to develop a method to examine how evaluation (formative and summative) is integrated into STEM activities by mathematics and science teachers. In particular, she will examine how teachers integrate academic requirements from governance documents into their STEM lessons. Additionally, she will study how evaluation (of academic content) contributes to the learner's affect-related experience. The next step is to develop a method for exploring these two themes during the activities of 10 STEM "laboratories", each with six teachers.

The poster by den Braber, Kruger, and Mazereeuw proposes to monitor in-service teachers who take an elective course in which they are stimulated to have conversations about their thoughts on the relevance of mathematics outside the classroom and to document their thoughts through reflections. Despite the 500-year tradition in Dutch mathematics teaching of grounding students' initial mathematical explorations in the real world, both teachers and students still have difficulty seeing the relevance of mathematics in their world. The authors' conjecture is that reflecting on the relevancy of mathematics in the elective course will support their thinking about teaching interdisciplinary courses and how to help their students reflect on the role and relevance of mathematics.

The poster by Ortiz-Laso, Diego-Mantecón, García-Fernández and Sanz-Ruiz aimed to identify the mathematics emerging under a biology-geology-mathematics integrated approach implemented by science and mathematics teachers, and to assess whether the numbers and algebra content appearing across the seven units was addressed as requested in the curriculum. The findings indicate that algebra was not integrated significantly due to the fact that the science teachers reported they did not feel prepared to teach algebra. In addition, science and mathematics teachers had disagreements about what content should be emphasized in the lessons, with all teachers focusing so much on “fusing” both disciplines that they overlooked the mathematics that was integral to those grade levels. The findings indicated that the integrated mathematics and science curriculum required continuous teacher development or co-teaching involving educators from different specializations.

Conclusions

Issues from the presentations and discussions during TWG26 can be summarized under three main points as follows. Firstly, there is still some question regarding the extent to which STE(A)M is expected to address all letters of the acronym or if it is sufficient to address two or more. Expanding on that, there is also disagreement about the nature of the “fusing” of these disciplines in STE(A)M lessons. Are each of the disciplines’ goals and practices the same, complementary or very distinct? Answers to this question have clear implications for the design approach for STE(A)M programs. Secondly, teachers experience difficulties when designing STE(A)M lesson plans because of insufficient content knowledge in their non-primary discipline. In addition, it is difficult to know how to integrate STE(A)M subject matters, how to design STE(A)M tasks and implement them with students. To overcome the difficulties teachers face, coaching, providing professional development programs, providing examples and materials to them, and facilitating collaboration with teachers from different disciplines to design lesson plans are essential. Lastly, promoting sustainability in a STE(A)M professional development program is needed.

Presentations and discussions raised questions and needs regarding the structural and systematic changes needed to support STE(A)M. In this regard, TWG26 participants agreed that various questions and needs should be considered: 1) where do we integrate STE(A)M units or lessons (separate courses or within each discipline)?, 2) when children go out of the classroom environment to learn STE(A)M, how do we transition them back to the more mathematical/school environment?, 3) should teachers be expected to design their own STE(A)M tasks to be implemented in classrooms or should they adapt already designed/researched materials?, and 4) how do we design collaborations between companies, organizations, other STE(A)M professionals and schools to deliver authentic STE(A)m experiences for students?

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