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Introduction to the papers of TWG16: Learning Mathematics with Technology and Other Resources

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Scope and focus of the Working Group

The scope of this working group is to address opportunities and possibilities, as well as challenges and limitations, of information and communication technology (ICT) and other resources for student learning (see Trgalová, Clark-Wilson & Weigand 2017). ICTs include software programs, various kinds of hand-held devices, online and classroom activities, and sensors. In addition, ICTs are considered in relation to more traditional non-digital resources such as textbooks, worksheets and various types of tools and physical manipulatives. We want to establish an overview of the current state of the art research in technology use in mathematics education, including practice-oriented experiences, research-based evidence, and theoretically enriched perspectives, as seen from an international perspective and with a focus on student learning. We also aim to suggest important trends for technology-rich mathematics education in the future, including a research agenda. Even though TWG 15 is closely related to this theme, it focuses more specifically on the role and practices of the teacher.

In TWG 16, we had 28 presented papers and 14 posters. To promote more indepth discussions, we split up for some sessions into TWG16a and TWG16b.

Relevant topics

In TWG 16, we might roughly classify the presented topics as follows:

- **Content-related topics:** rational numbers, variables, stochastics, multiplicative reasoning, equation transformation, functions;
- **Assessment:** assessment with Dynamic Software Systems (DGS), digital tests (possibilities and limitations), self-assessment, feedback, especially also with ITS;
- **Modelling:** understanding the process of modelling, giving special examples like the “Math City Trail – a mathematical journey through a city”, long-term effects of modelling;
- **Specific tools:** APPs, dynamic geometry, graphic calculators, virtual and augmented reality;
- **Activity structures:** gamification, online courses, flipped classroom, collaborative work.
- **Theoretical perspectives:** activity theory, embodied cognition (esp. gestures).

Some Comments on the result of the TWG 16

Assessment

Assessment is an important part of the teaching and learning of mathematics. On the one side, it is associated with the evaluation of student knowledge and learning at the end of a course or teaching unit (summative assessment). On the other side, assessment should provide constant feedback to students during the learning process (formative assessment). Digital technology can be used in or can enhance both summative and formative assessment in many different ways. Three examples from this TWG: *Irene van Stiphout & Madelon Groenheiden* reflect on the construction of a digital diagnostic test for middle school in the Netherlands. They focused on the constant struggle between testing higher order skills, concrete description of curriculum goals on the one hand, and the limited possibilities of the digital test environment on the other hand. *Yael Luz* describes a pilot experiment in adaptive assessment. A system that automatically analyzes answers and generates immediate feedback is developed. Finally, *Sietske Tacoma, Bastiaan Heeren, Johan Jeurig and Paul Drijvers* investigate how providing automated feedback in an Intelligent Tutoring System can help students in an introductory university statistics course. Over all, assessment will remain a very relevant topic in the years to come.

The big variety of digital tools

It is very difficult to give an overview of present forms of digital technologies. On the one hand, there are still the classical software programmes used like computer algebra systems, dynamic geometry software, and spreadsheets. *Markku Hannula & Mika Toivanen* use Geogebra for problem solving activities and give a critical view to the use of computers, *Edith Lindenbauer* shows how Geogebra can be used to develop functional thinking. *Myrto Karavakou & Chronis Kynigos* create connections among different aspects of trigonometric functions in a programming environment. Some new features have been added to this traditional software, especially 3-D-geometry. On the other hand, mobile technology like tablets and smartphones with a big variety of apps are becoming more and more embedded in students' lives, which leads us to consider their wider use as an educational resource. For example, *Chorney, Gunes & Sinclair* presented the multi-touch App *TouchTimes*, which is designed to support multiplicative thinking. At TWG 16, there was also a first glance of the use of virtual and augmented reality for the learning and teaching process. This will be a very relevant topic for the future, too.

Elementary School

Learning how to use digital technologies starts in Kindergarten and Elementary School. Therefore, it is very important to discuss and evaluate chances and possibilities, but also restrictions and difficulties of the use of software in Elementary School as done within the TWG 16. For example, *Ana Donevska-Todorova & Katja Eilerts* develop criteria for reviewing the quality, potentials and limitations of tablet apps for elementary geometry. *Eitan Ben-Haim, Anat Cohen & Michal Tabach* discuss the suitability of the character of the graphic design on the students' achievements while engaging with mathematical applets. *Melanie Platz* creates a learning environment applying digital learning tools to support argumentation skills in primary school. *Axel Schulz & Daniel Walter* create the tablet-app 'Stellenwerte

üben' (Practicing place value)¹ for practicing the place value concept. They show that previous experience with concrete physical material overlaps and influences the intended use of the implemented virtual features. Finally, an exploratory study by *Sean Chorney, Canan Gunes & Nathalie Sinclair* with *TouchTimes* focuses on how students interact with a new model of multiplication inspired by Davydov's unitising approach, and, in particular, how they develop particular two-handed gesturing practices that involve coordinating two quantities—multiplier and multiplicand—in an embodied way. They argue that this approach provides an alternative to the model of repeated addition, which is frequently over-used in students' initial encounters with multiplication.

Online courses

Nowadays, there is a variety of online courses. They are used mainly at the university level as a substitute for face-to-face lectures. There are “blended learning” approaches in which the online course is used as an additional resource to face-to-face courses, or as an optional resource for special topics, which are not in the mainstream of traditionally taught topics, or as remedial courses (especially for first-year students) that cover basic school mathematics topics. Online courses pose many didactically interesting questions, e.g. how to present the topics, the effect of online in comparison to face-to-face courses, and the behaviour of the students while working online. *Eirini Geraniou & Cosette Crisan* created an asynchronous course on the use of digital technologies in mathematics education where students are not interacting with the lecturer or their peers in real time. They evaluated how the tutors' design considerations and their online pedagogic strategies have influenced students' learning experiences and their engagement with its resources, such as content, peers and tutors. The results show on the one hand students liked the flexible mode of study, but on the other hand, they show the effect of the missing conversations among the students and the necessity of an orchestration of the timing of online contributions.

Games and gamification

Gamification is a topic of much discussion in relation to learning, teaching and motivation. Gamification means the transfer of game principles, game design and game strategies to external fields, like the learning and teaching of mathematics. *Carlotta Soldano & Cristina Sabena* developed game-based activities within a dynamic geometry environment—e.g. one player drags a vertex of a dynamic geometric configuration and the other player must respond in a way that maintains or breaks a constraint—for primary school to foster the development of students' mathematical understanding and their argumentation competencies. *Georgios Thoma* examines problem-solving techniques in the context video games and illustrates the game's potentiality as a problem-solving environment.

The growing variety of theories

The vast and diverse amount of theories related to technology implementation in mathematics education, as already reported in previous CERME research (e.g. Donevska-Todorova & Trgalová, 2017) brings the challenge of their applicability and relatedness with appropriate research methods. There are some well-known theories from other scientific disciplines as the

¹ The German version of the tablet-app is provided on Google Play. An English version is in progress.

theory of instrumental genesis, the theory of semiotic mediation and activity theory. There is also a growing interest in theories of embodied cognition, particularly in relation to the use of technologies that offer new ways for students and teachers to express themselves mathematics, through gestures and other body movements, as in the work by Chorney, Gunes and Sinclair. Given the plenary lecture by Paul Drijvers, who also promoted the incorporation of theories of embodiment into existing theories (such as instrumental genesis), and the growing number of non-dualistic theories of learning (of body and mind), we anticipate that this will become an area of fertile growth and change in the upcoming years.

Some thoughts about upcoming topics

A guideline of TWG 16 is to envisage upcoming trends and topics in relation to digital technologies. Online-courses, assessment and gamification are present topics which should be of great interest to mathematics educators and educational researchers in the coming years. There are other topics, which are also represented in the papers of TWG 15. One is space geometry. *Xavier Nicolas & Jana Trgalova* created a virtual environment dedicated to spatial geometry to support the development of vision in space. Another topic is the use of digital technologies in out-door mathematics. *Joerg Zender & Matthias Ludwig* created the mobile app MathCityMap, which poses questions and provides help for questions posed while students do a math trail in the city. *Osama Swidan & Eleonora Faggiano* see modelling under a semiotic lens. While modelling activities are introduced by dynamic digital artefacts, they want to understand the ways students' transit between the simulation of real phenomenon and the mathematical representation. Interesting and challenging is for sure the relation of school mathematics and social media, or digital culture and school culture. *Giulia Bini & Ornella Robutti* use "Internet Memes" combined with augmented reality (AR) technology, to "cultivate classroom discourse and maximize linguistic and cognitive meta-awareness in high school students" (Abstract of the paper). *Florian Schacht & Osama Swidan* address pre-calculus concepts using augmented reality-technology. They use technology design-principles to create an AR-environment, to address technological constraints experienced in experimental situations and discuss alternative ways. And finally, flipped classroom situations (see the paper of *Stefanie Schallert & Robert Weinhandl*) have to be investigated in more detail concerning the learning outcome.

Finally, as technology moves from being an epiphenomenal part of our lives, and of classroom practice, we anticipate that in future CERMEs, many of the content-specific contributions will migrate to other TWGs, as might contributions focused on themes such as assessment. This may be a healthy shift in mathematics education research.

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