TG2 Panel:
Digital Tools for Mathematic Education and Instrumental Reasoning

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This is a summary of the *TG2 Panel: Digital Tools for Mathematic Education and Instrumental Reasoning* that took place at the Symposium on Artificial Intelligence for Mathematics Education (AI4ME), held at CIEM Castro Urdiales, February 28th - March 1st, 2020.

Summary

This panel focused on digital technologies supporting learners' mathematical activity. The three following interventions illustrated various roles digital tools can play in mathematics education and thus support mathematics learning:

1. Robert Corless and Eunice Chan in their contribution *Teaching programming to mathematics scientists* shared their experience with a blended course on computational mathematics. Programming visually appealing Newton fractals and other playful activities with Maple or Python not only helped students overcome difficulties frequently encountered when learning programming, but also triggered better conceptualization of mathematical notions at stake.

2. The contribution *Understanding and creating to better understand instrumental proof using QED-Tutrix* by Philippe R. Richard presented new developments of a system specifically designed to supports students in solving problems of proof. The system embeds a virtual pedagogical agent capable of following students solving a proof problem, which is based on the referential of school mathematics properties and definitions. The new developments consist in considering, besides verbal justifications of inferences, a wider range of justifications, such as justifications provided by a technological tool, the construction of a dynamic figure, or the execution of an algorithm.

3. Tomás Recio in his contribution *Towards a mechanical geometer* reported about a development of a system aiming at automated discovery of properties in elementary geometry recently implemented to Geogebra. The

capability of the system to discover and prove geometric properties raises important didactic issues about the role of digital tools in mathematics teaching and learning or the impact of digital tools on mathematics curricula.

Discussions triggered by the presentations brought to the fore several important issues related to the theme and led to questioning the very link between artificial intelligence and mathematics education.

First, when digital tools are referred to in relation with mathematics education, one naturally thinks about tools supporting students' learning of mathematics, such as Geogebra, Maple or QED-Tutrix, to name only those that were mentioned in the presentations. These tools support students' mathematical activity, and consequently their learning, by providing mathematical or didactic feedback [Balacheff, 1993]. Whereas mathematical feedback aims at helping students make sense of the phenomena observed on the interface (e.g., invariance of geometric properties while dragging free points in Geogebra), the role of didactic feedback can be to evaluate students' responses (true or false) or to support them in the task resolution (e.g., scaffolding as in QED-Tutrix). The latter usually requires deeper didactic analysis of the mathematical domain at stake and of the possible students' reasoning strategies in order to provide relevant feedback in response to students' actions [Nkambou et al., 2010]. On the other hand, digital tools providing teachers with information about their students to help their decision making are scarce [Nikolayeva et al., 2018, Pilet et al., 2013]. The development of such tools benefits from artificial intelligence methods to model students' (mis)conceptions and pedagogical strategies and to compute adequate didactic responses to students' actions.

Another important issue that was raised during the discussions concerned the potential of digital tools. Some tools offer the possibility to provide a-didactic milieu [Brousseau, 1997], with which the students interact and get (mathematical) feedback that they need to interpret (e.g., Geogebra). Other tools create a didactic milieu with explicit (didactic) feedback, for example about the validity of the provided response or suggesting next step in the problem solving (e.g., QED-Tutrix). Yet some other tools amplify the user capabilities by providing answers (e.g., Maple) or performing tasks (e.g., Geogebra Automated Geometer). The availability of such tools raises a number of questions, in particular:

1. Do the students need to learn how to solve tasks the tool can solve? This question addresses the issue of the impact of the use of digital tools on mathematics curriculum.
2. How can such potential of digital tools be exploited for purposes of mathematics teaching and learning? This question opens avenues toward designing new types of tasks.

Regarding the instrumented learning, the discussions brought to the light the importance of considering the semiotic potential of the digital tool [Mariotti and Maracci, 2010] in order to be aware which mathematical meanings it conveys. Instrumental issues need also to be taken into account: indeed, while using a tool to accomplish a given task, a user develops a personal instrument [Rabardel, 2002] that can differ from one user to the other, depending on their knowledge or beliefs. These considerations lead to rethink the role of the tutor, whether human, virtual or blended, which may change in a digital environment, but remains crucial in accompanying the students toward the achievement of the target educational goal.

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