





THE NETHERLANDS

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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 et 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 Höim	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 asked 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.

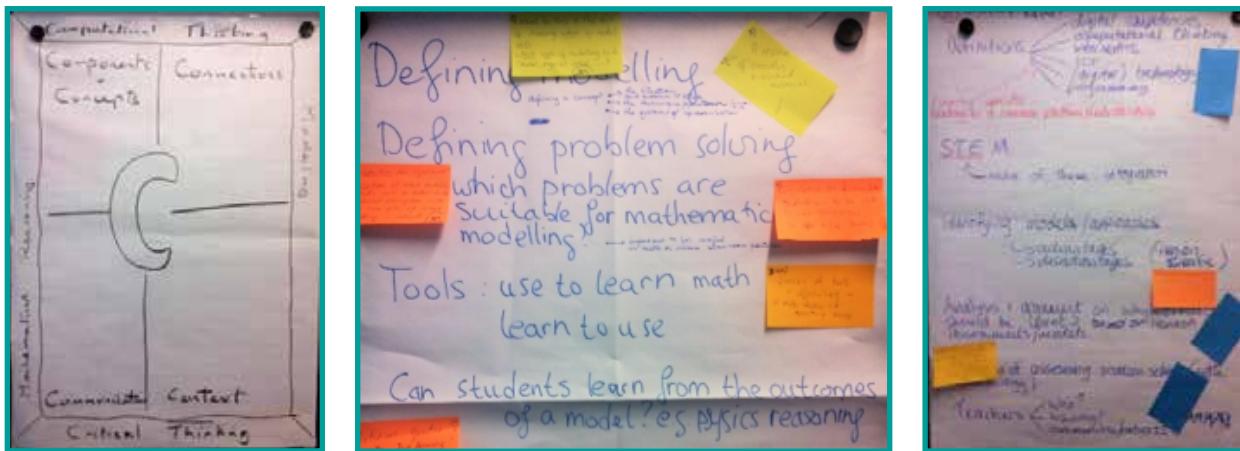
Finally, participants compiled a final version of their paper, in which they were able to process their experiences from the meeting. The resulting papers can be found at <http://rekenenwiskunde.slo.nl/>.

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.

- 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 significantly¹ consider modelling to be a key student skill, when informatics is included in STEM, while mathematics has a substantial computer-based component.

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/algorithimize such modelling.
- Through the process of modelling, a student can show his or her deep understanding and can use his or her knowledge.

¹ $p=0,00000191 < 0,05$

- 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.

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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 significantly² 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 foremost 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 significantly³ 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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