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Teaching approaches and educational technologies in teaching mathematics in higher education: An international survey

Abstract

The growing use of technology in higher education in mathematics education involves new pedagogical and technical challenges for teachers. We analysed teaching approaches and technology-related pedagogical competencies of 29 mathematics teachers from nine European countries. We conducted interviews and applied the Approaches to Teaching Inventory (ATI 16) and the Technological Pedagogical Content Knowledge framework (TPaCK) survey. Results show large individual variations of teaching approaches, technological competencies and institutional support. Educating and supporting teachers in embracing educational technologies thus needs to be tailored strongly to the individual needs and the available institutional support.

Keywords

Mathematics education, Approaches to teaching, Educational Technologies

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1 Introduction

The current situation with the Corona pandemic emphasizes that teachers of higher education institutions need to have sufficient skills in online teaching. Institutions are thus recommended to provide adequate training for teachers to increase their skills for online teaching (Kafyulilo, Fisser, Pieters, & Voogt, 2015).This is also true when teaching mathematics.

For teaching mathematics, it is not enough that teachers have content knowledge, thus know what to teach. Instead, teachers also need pedagogical knowledge on how to teach and how to deal with student's problems and misunderstandings (Yigit, 2014). Additionally, teachers should have knowledge of the appropriate use of educational technologies.

The use of technologies for mathematic teaching and learning can be classified in two dimensions: First, the use of domain-specific mathematics tools; and second, the general use of learning technologies and online tools (Crawford, Abdulwahed, & Jaworski, 2012). Education and technology have become two interdependent concepts in mathematics education (Kirikçilar & Yildiz, 2018).

Consequently, a low digital literacy of mathematics teachers may hinder the adoption of modern pedagogical and technological approaches in mathematic learning and teaching (Crawford et al., 2012).

Nowadays, many teachers adopt the perspective that learning can only be successful if learners construct their knowledge and do not only memorize knowledge (Kirikçilar & Yildiz, 2018). Teachers thus may help students to use and reinforce the knowledge they have and to produce new knowledge. In this case, the teaching approach is changing from a teacher-centred to a more student-centred approach.

Calls for reforming mathematics education by considering more innovative teaching approaches are often rooted in constructive theory (Crawford et al., 2012). Student-centred teaching approaches play an essential role in this process. Student-centred teachings approaches such as Problem-Based Learning have thus been developed and started to be used in mathematics education (Crawford et al., 2012)

To foster innovative pedagogical and technical approaches to mathematics education, the Erasmus+ project (ITEM) “Innovative Teaching Education in Mathematics” started in 2018 (ITEM, 2019). The objective of ITEM is to train mathematics teachers in new teaching approaches and in using educational technologies in teaching mathematics.

2 Background

The Erasmus+ project ITEM aims at improving mathematics teaching practice in higher education by applying innovative instructional approaches. Mathematics is essential in addressing major challenges in science, technology and engineering. The main objectives of the ITEM project is to change the way Mathematics is being taught within higher education to increase students’ motivation to build their mathematical skills, to increase students’ success rate in mathematics courses. To achieve this, one aim is to improve teaching quality and enrich teachers´ toolbox with engaging teaching techniques.

Consequently, the ITEM project has started to organize workshops for mathematics teachers of the participating universities to train them in student-centred methods such as Problem-Based Learning (PBL) and Project-oriented Problem-Based Learning (POPBL) as well as to train them in the usage of educational technologies (learning management systems, mathematics software such as GeoGebra).

Problem-based learning (PBL) is an active pedagogical student-centered learning method. It requires a change of an educational practice where the teacher is at the center. Savery (2006) defines PBL as an “instructional (and curricular) student-centered approach that empowers students to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem”. (Savery, 2006). The central element of PBL is the problem which is a real-life situation that helps to start the learning process. The assumption is that students are ready to learn when faced with a problem that cannot be resolved with the knowledge they have. Since we do not know the solution to the problem, we start looking for new sources of information and knowledge to resolve it. Another aspect is, that students learn from each other, therefore working in groups is another fundamental aspect. (Savery, 2006)

To govern the workshops for using educational technologies in teaching mathematics, we use the TPACK framework. This theoretical framework of Technological Pedagogical Content Knowledge (TPACK) can be used to describe what teachers need to know to successfully integrate technology into teaching mathematics.

The TPACK framework comprises seven domains: The Technological Knowledge (TK), the Pedagogical Knowledge (PK), the Content Knowledge (CK), the Technological Content Knowledge (TCK), the Technological Pedagogical Knowledge (TPK) and the Technological Pedagogical Content Knowledge (TPACK) (Mishra & Koehler, 2006):

Content knowledge (CK): Content knowelege is about learning and teaching the subject. It refers to sujects in the field to be taught.

Pedagogical Knowledge (PK): Teacher's knowledge of teaching methods, strategies and techniques used in the classroom.

Technology Knowledge (TK): Teacher's knowledge of educational technologies and technical infrastructures (software, hardware, internet, tablet). Technology knowledge is the information and skills that teacher should habe in using technology.

Pedagogical Content Knowledge (PCK): Teacher's knowledge of effective use of teaching methods and techniques to teach the contents of the course. The teacher knows how student´s learn and how to measure and evaluate the learning outcome.

Technology Content Knowledge (TCK): Teacher's knowledge of using the appropriate technology for educational to teach the contents.

Technology Pedagogical Knowledge (TPK): Teacher's knowledge of effective pedagogical use of educational technology. That refers knowledge of tools and its functionalities, as well as on the interrelation between tools and tasks.

Technological pedagogical content knowledge (TPCK): Teacher's knowledge of the effective combination of pedagocypedagogy and educational technology for teaching mathematical content.

TPACK has successfully been used as a framework to analyse and improve teaching in science and mathematics teaching in higher education (Salas-Rueda, 2019; Rienties et al., 2013).

Objective

We aim at exploring teaching approaches and technology-related pedagogical competencies of the mathematics teacher involved in ITEM, to be able to prepare and tailor the teachers' training programs within the ITEM project.

The research question are:

Q1: Which teaching approaches are applied by mathematics teachers in higher education?

Q2: From the perspective of TPACK, which content-related and technological knowledge do the mathematics teachers show?

Q3: Based on results from Q1 and Q2, which areas should be covered in the workshops for the ITEM teachers to better prepare the mathematics teachers for student-centred teaching?

3 Method

This study takes a mixed-method approach to answer the study questions. We combined qualitative semi-structured interviews with two standardized surveys, the "Approaches to teaching inventory (ATI)" survey and a TPACK survey.

The qualitative interviews were intended to get context information on teaching and technical infrastructures of the participating universities. The quantitative survey aimed at getting comparable data among participating teachers, and to serve as a premeasurement for later planned post-measurements, after conduction of the teachers' training programs within the ITEM project.

3.1 Qualitative interviews

We conducted ten semi-structured interviews with mathematics teachers of courses in linear algebra and calculus from ten higher education institutions participating in ITEM. The interviews were conducted via online video calls between June and September 2019.

The interviews focused on two main topics: First, they focused on the use of technology in teaching mathematics and on the available technical infrastructure. For example: Do you use special software for teaching mathematics? And if so, which and in which form? Are the students invited to use their smartphones, tablets or laptops in your classroom? If yes, for which purpose? Do your classroom offer Wifi?

Second, interviews focused on using student-centred teaching approaches. For example: Are you using real-life examples and problems from other fields (e.g. biology, economy, physics) to teach mathematics? Are they elective activities where your students have to do their research on selected mathematics topics?

Overall, ten mathematics teachers from ten institutions of higher education of seven countries participated in the interviews: Kosovo; Uzbekistan; Greece; Republic of North Macedonia; Israel, Czech Republic; Sweden. The duration of interviews was between 15 and 35 minutes.

We conducted a summarizing transcription and categorization of the statements of the interviews on two major topics: Use of technology in teaching mathematics, and personal teaching approaches.

3.2 Quantitative standardized ATI and TPACK survey

We used the "Approaches to Teaching Inventory" (ATI 16) of Trigwell & Prosser (2004), a validated instrument with 16 items measuring two approaches to teaching.

This instrument allows us to measure two opposing approaches to teaching, the information transfer/teacher focus (ITTF) approach and the conceptual change/student-focused (CCSF) approach. The ITTF approach corresponds to a more teacher-centred strategy, while the CCSF approach corresponds to a more student-centred strategy (Trigwell & Prosser, 2004).

To assess the TPACK dimensions of technological, pedagogical and continent knowledge, we used a modified version of the HE-TPACK instrument (Garrett, 2014). This instrument measures the TPACK level in higher education (HE). Originally, this instrument contained 57 items. The modified version we used consisted of 26 items, including demographic information.

All mathematical teachers within ITEM who were nominated to participate in the proposed training workshops during the ITEM project were invited to the survey. Overall, 61 teachers from 13 different universities in nine countries were invited to fill in the online survey between August and September 2019. The survey was conducted before the first ITEM teachers' workshop training that took place in October 2019.

Participants were asked to answer both surveys by considering the most typical course that they teach. Survey items could be answered on a five-point Likert scale (from 1 = only rarely true, to 5 = almost always true). Results of the ATI CSSF scale and the ATI ITTF subscale were calculated for each respondent by calculating the mean of the corresponding items.

Overall, 29 mathematics teachers responded to the survey (response rate: 48%). Half of the respondents were female. Overall, 27% of respondents had more than 20 years teaching experience, 24% had between 15 to 19 years, 21% between 10 to 14 years 14% between 5 to 9 years and 14% of respondents had less than 5 years experiences in teaching between 1 to 4 years.

4 Results

We first present the results of the interviews and then the results of the ATI and TPACK survey.

4.1 Use of technologies in teaching mathematics

In this part of the interviews, we focused on the technologies the teachers use in their classes.

Two (of the seven participating institutions) use Moodle as a learning management system (LMS). The other institutions use different LMS (e.g. E-Class, Canvas) one institution does not use any kind of LMS. Most of the teachers indicated to use the platforms only to provide slides for the upcoming lessons (*"I scan my handout and give them a file. They can submit their hand in"; "For the materials, we use google drive").* Only one teacher uses the learning platform as an interactive tool with students. A university-wide strategy in using an online learning platform is not mentioned among any of the interviewed teachers.

Nearly all interviewed teachers are using special mathematics software to help students to learn mathematics. Often mentioned tools comprise Matlab, GeoGebra, Kahoot, Desmos and Derivative Calculator (*"To use tools in the lectures to illustrate things. We use that to draw things and drafts. To pictures on the board. We use it also for hand in assignment*"; "*It is a quite useful thing. The students use it also – we try to encourage them").*

All teachers have WiFi available in their classroom. Students mostly bring their private devices and use them in class. Only one university does not allow the use of smartphones or tablets in classes.

4.2 Teaching approaches in mathematics

This part of the interviews focused on using student-centred approaches in teaching, and especially on using problem-based learning based on real-life examples. Nearly all teachers already try to work with real-life examples especially from physics. Only few use examples from mechanics, electronics or engineering. One teacher has the opportunity to work with examples they get from the partner of the industry: *"At this practice part, the students have to solve real-life questions in Team of 4 to 5."*

Most teachers state that they use real life examples to catch the interest of their students and to show how mathematics is applied to real life problems: *"So it is a kind of entertaining math. Because every students consider that math is difficult"; "We all change the way to teach mathematics. We need applied mathematics for our students."* Mostly, the teacher prepares a list of real-life examples, and the students can then choose which one they want to solve.

We also asked the teachers whether they consider their teaching approach as more teacher-focused or more student-focused. Most of the teachers described their approach as student-focused. They explained that they try to encourage students to discuss topics during the lectures, or that they motivate students to work together in smaller student groups to improve learning. Fewer teachers considered their approach as more teacher-focused, with a focus on the presentation of content: "*The goal is to deliver math courses"*.

4.3 Approaches to teaching (ATI)

Figure1 shows the aggregated results of the student-centred subscale (CSSF) and the teacher-centred subscale (ITTF) of the ATI survey for all 29 teachers. The range for the conceptual change/student-focused (CCSF) subscale is 1.0 – 4.4. The range for the information transfer/teacher focus (ITTF) subscale is 2.0 – 4.3.

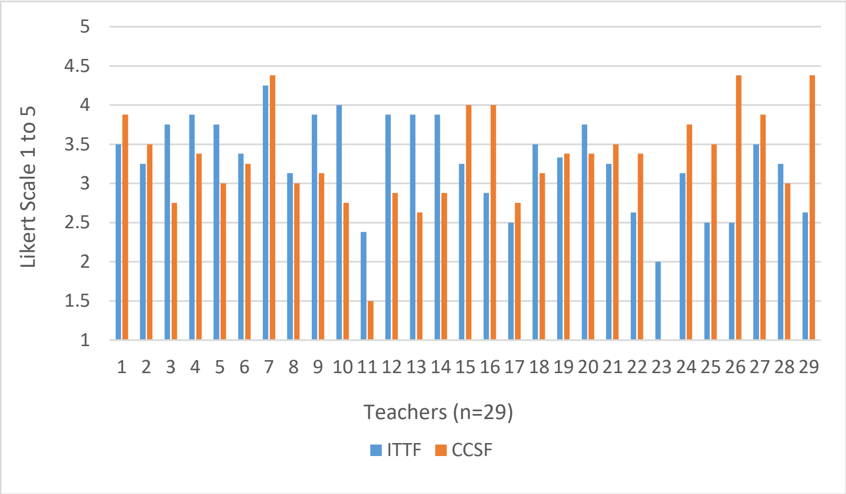

Figure1:Score of each teacher (n=29) in the category ITTF (teacher-centred approach) and CCSF(student-centred approach) of the Approches to teaching inventory (ATI).

The ATI survey calculates an individual teacher's score both for teacher-centred approach (ITTF) and for student-centred approach (CCSF) (Figure1). To better understand the overall teaching approach of a teacher, we subtracted the ITTF score from the CCSF score (Figure 2). For example, teacher 10 has an ITTF score of 4 and a CCSF score of 2.75. The overall score is 2.75 – 4 = -1,25 which is displayed in Figure 2. The higher the calculated score, the higher the student-centredness of an individual teacher.

Quantitative clustering of the results in Figure 2 shows three general clusters. First, teachers with a stronger teacher-focused approach (left part of Figure 2); second, teachers with a balanced approach (middle part of Figure 2); and third, teachers with a stronger student-focused approach (right part of Figure 2).

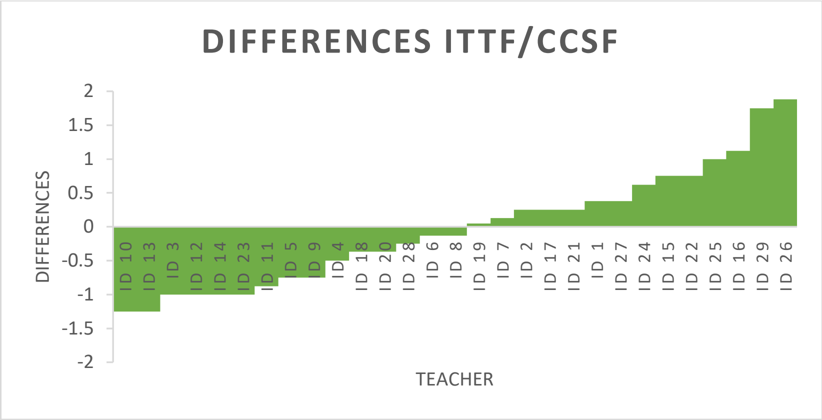

Figure 2: Differences of each teacher (n=29) between ITTF approach and CCSF approach. Negative value indicate more teacher-centred approach. Positive value indicate more student-centred approach.

These results thus show large individual variations in teaching approaches. To see whether the institution plays a role in the teaching approach, we compared results of the institutions participating in survey. No meaningful patterns couldn't found in this subanalysis.

4.4 Technology, pedagogical, content knowledge (TPACK)

Figure 3 and Figure 4 present the results of the TPACK survey of all 29 respondents.

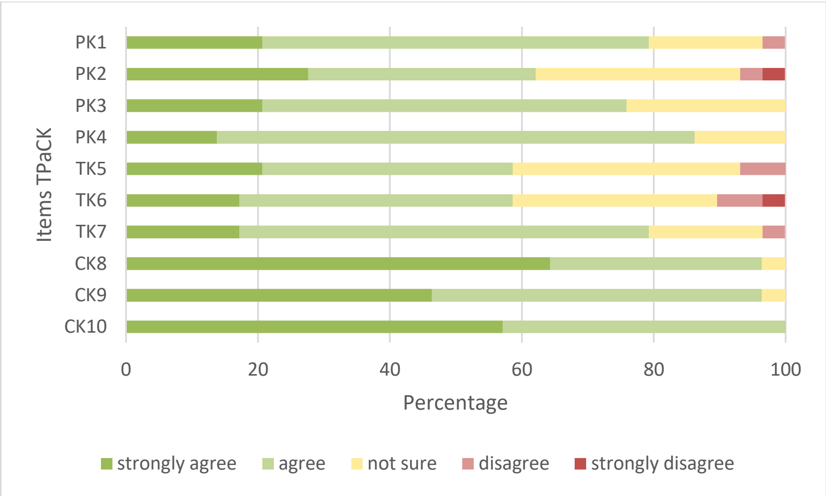

Figure 3: Results in percentage of each item of the TPaCK questions 1 to 10 (n=29)

<u>Questions to Figure 3:</u>

PK 1. I have a clear understanding of pedagogy (e.g., designing instruction, assessing students' learning).
PK 2. I am familiar with a wide range of practices, strategies, and methods that I use in my teaching.
PK 3. I know how to assess student learning.
PK 4. I know how to motivate students to learn.
TK 5. I am familiar with a variety of hardware, software and technology tools that I can use for teaching.
TK 6. I know how to troubleshoot technology problems when they arise.
TK 7. I can decide when technology can be beneficial to achieving a learning objective.
CK 8. I have a comprehensive understanding of the curriculum I teach.
CK 9. I explain to students the value of knowing concepts in my discipline.
CK 10. I make connections between the different topics in my discipline.

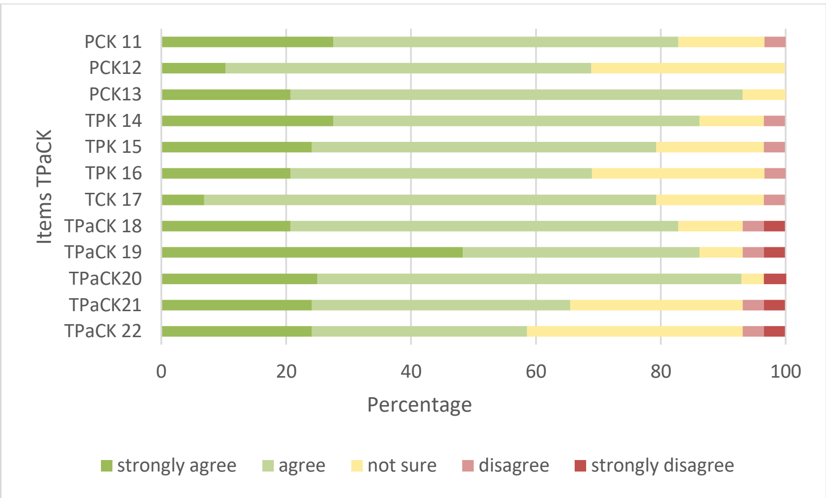

Figure 4: Results in percentage of each item of the TPaCK questions 11 to 22 (n=29).

Questions to Figure 4:

PCK 11: I understand that there is a relationship between content and the teaching methods used to teach that content.

PCK 12: I can anticipate and address students' preconceptions and misconception

PCK 13: I understand what topics or concepts are easy or difficult to learn

TPK 14: I understand how teaching and learning change when certain technologies are used.

TPK 15: I understand how technology can be integrated into teaching and learning to help students achieve specific pedagogical goals.

TPK 16: I know how to be flexible with my use of technology to support teaching and learning.

TCK 17: I understand how the choice of technologies allows and limits the types of content ideas that can be taught

TPaCK 18: I integrate educational technologies to increase student opportunities for interaction with ideas.

TPaCK 19: I motivate my students to use learning technologies to support their individual learning.

TPaCK 20: I understand what makes certain concepts difficult to learn for students and how technology can be used to leverage that knowledge to improve student learning.

TPaCK 21: I understand how to integrate technology to build upon students' prior knowledge of curriculum content.

TPaCK 22: I know how to operate classroom technologies and can incorporate them into my particular discipline to enhance student learning.

We clustered the seven questions with highest rate to strongly agree and agree and the seven questions with highest rate to disagree and strongly disagree. Details are shown in

Table1 and

Ranking	ITEM	disagree/ strongly disagree	TPACK Question
1	TK6	10%	I know how to troubleshoot technology problems when they arise.
2	PK2	7%	I am familiar with a wide range of practices, strategies, and methods that I use in my teaching.
3	TK5	7%	I am familiar with a variety of hardware, software and technology toolsthat I can use for teaching.
4	TPaCK 18	7%	I integrate educational technologies to increase student opportunities for interaction with ideas.
5	TPaCK 19	7%	I motivate my students to use learning technologies to support their individual learning.
6	TPaCK21	7%	I understand how to integrate technology to build upon students' prior knowledge of curriculum content.
7	TPaCK 22	7%	I know how to operate classroom technologies and can incorporate them into my particular discipline to enhance student learning.

Table 2.

Ranking	ITEM	agree/ strongly agree	TPACK Questions
1	CK10	100%	I make connections between the different topics in my discipline.
2	CK9	96%	I explain to students the value of knowing concepts in my discipline.
3	CK8	96%	I have a comprehensive understanding of the curriculum I teach.
4	PCK13	93%	I understand what topics or concepts are easy or difficult to learn
5	TPaCK20	93%	I understand what makes certain concepts difficult to learn for students and how technology can be used to leverage that knowledge
6	PK4	86%	I know how to motivate students to learn.
7	TPK 14	86%	I understand how teaching and learning change when certain technologies are used.

Table1 : Items of the TPCACK survey that were most often rated as agree and strongly agree (n = 29).

Ranking	ITEM	disagree/ strongly disagree	TPACK Question
1	TK6	10%	I know how to troubleshoot technology problems when they arise.
2	PK2	7%	I am familiar with a wide range of practices, strategies, and methods that I use in my teaching.
3	TK5	7%	I am familiar with a variety of hardware, software and technology toolsthat I can use for teaching.
4	TPaCK 18	7%	I integrate educational technologies to increase student opportunities for interaction with ideas.
5	TPaCK 19	7%	I motivate my students to use learning technologies to support their individual learning.
6	TPaCK21	7%	I understand how to integrate technology to build upon students' prior knowledge of curriculum content.
7	TPaCK 22	7%	I know how to operate classroom technologies and can incorporate them into my particular discipline to enhance student learning.

Table 2: Items of the TPCACK survey that were most often rated disagree and strongly disagree (n=29).

5 Discussion

We analysed the teaching approaches of 29 mathematics teachers in higher education. In the interviews, the majority of teachers indicated to use a more student-focused approach. The ATI survey showed large individual variations, with around one-third of teachers applying a more student-centred approach, one-third applying a more teacher-centred approach, and one-third applying a mixed approach. As an indicator of a student-centred approach, most interviewed teachers said to use real-life problems, mostly from physics.

The TPACK survey showed high support for content-related items, but low support for technology-related items. The interviews showed that learning platforms are mostly used to share materials, but nearly never for interactive or self-regulated activities. While WiFi is available in most classes, this is mostly used by students for following the lecture, but not use by the teacher for activating activities during the classroom. Overall, the support of TPACK items that address the interaction of technology, pedagogy and content is quite low.

Based on these results, we see a strong need for continuous training of the mathematics teachers in two fields: First, using technology in teaching, especially using technology for fostering student-centred teaching. Second, better understanding how technology can support content-related pedagogy. These findings are already discussed within the ITEM consortium and will help to shape future teachers' training workshops.

As a limitation, this study only teachers already involved in ITEM. The results show that their teaching approaches and institutional contexts are quite diverse, so we expect our findings to be relevant also for other higher educational institutions. However, given the convenience sampling we applied, the results can not be seen as representative for the involved institutions or for mathematics teaching in general.

During the interviews, when discussing their teaching approach, we had the impression that many teachers had not yet really thought about their approach. For example, when asking whether their teaching is more student-centred or more teacher-centred, teachers answered that they have a student-based evaluation of their courses and thus consider their approach student-centred. The standardized ATI survey provides a more clear and standardized picture of the student- versus teacher-centredness of the respondents and shows large variety in student-centrendness.

We had expected to see some patterns of teaching approaches between institutions, but the sample size was too small to derive meaningful patterns.

We developed a new approach to substract the ATI student-centred scale from the ATI teacher-centred scale, to get a better picture of the individual teaching approach. We were not able to validate this approach based on the ATI literature. No formal validation of the resulting score has yet been done, but should be done in a future project.

Within the ITEM projects, training workshops for ITEM teachers are now being conducted. We plan to repeat the ATI and TPACK survey with the same teachers upon completion of the training. We would in general expect an increase in student-centred approaches and technology-related and technology-pedagogy-related knowledge.

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