Professionalising teachers with a digital formative assessment tool: a case study of the SMART tests

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SMART, a digital formative assessment tool for mathematics education, aids teachers by offering short online diagnostic checks and detailed analyses of response patterns. It identifies student misconceptions and provides teachers with valuable insights on students' level of understanding. This should have the potential to not only influence teaching and student understanding but also the teachers' professionalisation. This paper explores the potential impact of using SMART on five mathematics teachers' PCK in elementary algebra. Initial findings indicate the tool's effectiveness in enhancing teachers' knowledge of student thinking and typical mistakes.

Keywords: Technology-supported formative assessment, PCK, teacher professionalisation

Theoretical background

Formative assessment has been proven to be a valuable approach for students to benefit in their learning. Andrade & Heritage (2018) concretise that a successful implementation of formative assessment consists of a diagnosis of students' performance and progress, and an adjustment of teaching to the individual needs, for example by reacting to diagnosed misconceptions. Busch et al. (2015) have investigated teachers' formative assessment practices and found out, that content specific pedagogical content knowledge (PCK) has a high impact on diagnostic practices. They observed a shift from superficial diagnoses (e.g. just correcting mistakes) to a deeper analysis as soon as aspects of content specific PCK are shown. The PCK of teachers is often divided into different equally meaningful aspects, e.g. in the COACTIV study it was defined as *knowledge of explaining and representation*, *knowledge of student thinking and typical mistakes*, and *knowledge of the potential of mathematical tasks.* This framework has demonstrated predictive validity in enhancing instructional quality and fostering student learning gains across various studies (Krauss et al., 2020).

Technology has the potential to support teachers in formative assessment processes while also developing the needed PCK of teachers (Stacey & Wiliam, 2013). One example of technology-based formative assessment is the SMART system, which provides a fast and in-depth diagnosis by specifically designed diagnostic items and their deep analysis (Stacey et al., 2018). After students complete a 5- to 10-minute test, only the teachers receive an automated diagnosis for each student in the form of comprehension levels and misconceptions. In addition, further explanations and teaching suggestions are provided, which include tips for teaching, general advice on rituals, attitudes, methods and desirable concepts, as well as concrete tasks that can be used directly to support the individual students (Price et al., 2013).

In this study we used a test from the field of algebra. The test *Meaning of Letters* examines whether students consistently interpret variables in such a way that they stand for numerical values and not as an abbreviation for objects occurring in the context. The test includes six multiple-choice items whose incorrect answer options reflect typical misinterpretations. For example, when the question is *"Biros are sold in packs of 3. Sam bought p packs and got b biros altogether. Choose the correct equation"*, the answer option *"3b = p"* can be understood as *"There are 3 biros in one pack"*, where the variables are interpreted as abbreviations for biros and packs respectively. This is known as the *letter-as-object* (LO) misconception (Stacey et al., 2018). This misconception is especially important since it can linger with students as they navigate their way through further algebra. Students who struggle to accurately formulate equations and expressions to represent real-world scenarios may miss out on harnessing the problem-solving potential of algebra. Given the accessibility of digital technology capable of solving equations, it becomes increasingly crucial for students to master the skill of constructing equations and accurately interpreting equations created by others, rather than focusing solely on solving equations manually (Arcavi et al., 2017). The SMART test compares the answer to the Biro item with the responses to similar items and searches for specific answer patterns to reveal if a student has this misconception.

The automatic diagnosis is displayed to the teachers in the form of three comprehension levels, based on the frequency on which this misconception is revealed. One additional misconception that the students may hold could also be flagged. The solution-as-coefficient (SAC) misconception is a subtype of the LO misconception, where a possible solution for an equation is already found and placed in front of the variables as coefficients. It is particularly important that teachers are able to recognise these misconceptions and know how to address them. Teachers who recognise that existing misconceptions may impede algebra learning can support their students by openly addressing the distinctions between coding, other notation systems, and the realm of algebra. Therefore the PCK aspect *knowledge of student thinking and typical mistakes* is particularly important for successful algebra teaching.

Research design

The nature of SMART tests suggests that teachers increase their *knowledge of student thinking and typical mistakes* while using SMART, because they engage with their own students' misconceptions and possible ways to overcome them. The aim of this study was to find out, to what extent a development of content specific PCK among teachers can be seen after using the SMART tests. To answer this question, five teachers of grade 7 participated in a pre-intervention-post-test design. The *knowledge of student thinking and typical mistakes* was surveyed in a pre-test with a competency test. As an intervention, they used the SMART test *Meaning of Letters* with their students and, based on the results, taught the topic of variables and their meaning for about 4 weeks. They then used a second version of this SMART test with their students to track student development. As a post-test, the teachers were surveyed with a second version of the competency test.

To test the PCK competency, an existing test by Busch et al. (2015) was adapted for algebra and understanding of variables. The analysis of the COACTIV study revealed that written tests were highly predictively valid for individual learning support (Krauss et al., 2020). In the competency test, four example student solutions were generated for teachers to assess. The examples represent typical student solutions to tasks on the understanding of variables and the concept of terms and equations and contain frequent misconceptions. Table 1 shows an example of one of the four examples in which the LO misconception is present. With the relevant *knowledge of student thinking and typical mistakes*, it can be recognised that this student does not interpret the variable as a placeholder for a numerical value, but rather as an abbreviation for an object (*m* stands for marshmallows). Additionally, the students' solution includes the correct answer as the equation (SAC) and is likely to be read as a solution sentence ("*4 marshmallows and 5 caramels together cost 80 cents*").

As a task to formulate linear equations, Anthony received the following task:
Catherine went into a candy shop: "I have bought marshmallows and caramels and paid a total of 80 cents. The marshmallows cost 10 cents each and the caramels 8 cents." Formulate an equation, that describes this situation.
Anthony wrote: $4m + 5c = 80$

Table 1: Example student solution "Candy shop" from the pre-test

The teachers were asked to formulate their own diagnosis as well as approaches for spontaneous and further supportive teaching practice. The teachers' answers were analysed in how far they could describe the possible student thinking and if they – implicitly or explicitly – refer to the underlying misconceptions the student may hold. The analyses of the pre- and post-tests were compared and examined for a development of PCK. The teachers' statements were qualitatively analysed by the first author and interrated by at least one other person.

Results

After examining the cases in how far they show *knowledge of student thinking and typical mistakes*, we were able to contrast three different ways of development: (1) two teachers showing implicit knowledge in the pre-test and becoming more explicit in the post-test, (2) two teachers showing no corresponding knowledge in the pre-test and showing implicit knowledge in the post-test, and (3) one teacher who constantly shows a lot of explicit knowledge.

As stated above, two teachers exhibited an implicit *knowledge of student thinking and typical mistakes*, primarily focusing on describing and evaluating the student's solution. For instance, they acknowledged the student's grasp of the situation but noted the inclusion of an unnecessary solution in the equation. Implicitly addressing the SAC misconception, the teachers lacked further explanation, failing to identify the underlying LO misconception. This gap was evident in the superficial and process-oriented supportive practices they expressed, in which they emphasised to highlight key information of the text and practice general strategies for text tasks. In the post-test, the teachers can identify slightly more precise that the student shows difficulties with the meaning of the variables. This becomes evident when they express possible supportive approaches in the post-test, because they focus on the meaning of the variable and suggest to "*write down what m and c mean*" and "*use simple number examples to check the solution*".

A similar development can be seen for two of the teachers who not only remained on a superficial focus in the pre-test ("*The equation does not make sense*"), but sometimes even diagnosed incorrectly and did not perceive the student's error at all. Accordingly, the supportive teaching practices remained predominantly at a general, motivational level ("*He should read the assignment again carefully*") or at a process-oriented level, vaguely suggesting that they would try to solve the equation together with the student. In the post-tests, these teachers showed a greater understanding of the student's difficulties, and the approaches show a more concrete connection to the task and the student's errors. For example, they suggest that the student should write the equation again without using the initial letters. This hints that these teachers show an implicit understanding of the LO misconception.

In one case, a teacher showed a consistently high *knowledge of student thinking and typical mistakes* in pre- and post-test ("*For Anthony, m seems to stand for the object marshmallows, and he is probably thinking of a spoken form of the equation: '4 marshmallows and 5 caramels cost 80 cents.' He apparently already has a solution in his head.*").

Discussion

The preliminary findings on SMART's impact on teachers' PCK are promising, as progress was seen for all teachers regarding the PCK aspect *knowledge of student thinking and typical mistakes*. While initial diagnoses had few variations, all teachers showed more explicit knowledge of underlying misconceptions to students' errors in the post-test. Those with implicitly recognisable knowledge in the pre-test became more explicit, utilising content specific terms. Teachers that struggled to explain student thinking in the pre-test could show implicit knowledge of the LO misconception in the post-test. Teachers with a lot of corresponding knowledge maintained this precision. These results align with the expectation that SMART increases teachers' *knowledge of student thinking and typical mistakes* and strengthens them to avoid an exclusive procedural knowledge focus. The presented cases are part of a broader study with over 40 teachers receiving various distinct interventions.

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