DIGITAL FORMATIVE SELF-ASSESSMENT

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Digital formative assessment tools rarely implement self-assessment even though self-assessment can support not only students' mathematical learning processes but also their metacognitive activities. The BASE project seeks to address this gap by developing a digital formative self-assessment tool (BASE tool) in which learners judge the correctness of their task solutions with the help of interactive sample solutions and task-related checklists. The paper first presents the design principles of the BASE tool and illustrates the self-assessment process using a multiplication task. Subsequently, we outline a theoretical framework for capturing the effects of the BASE tool on understanding and metacognition.

Keywords: self-assessment, digital feedback, mathematical understanding, metacognition, instrumental genesis

INTRODUCTION & THEORETICAL FRAMEWORK

Digital technologies can support formative assessment for example through dynamic and interactive visualizations (Yerushalmy & Olsher, 2020), adaptive feedback (Rezat, 2021), and individualized learning paths (Stacey & Wiliam, 2013). However, most digital formative assessment environments do not include self-assessments even though research has shown that "students benefit most when they develop the capacity to assess their own learning and evaluate the feedback they receive from other external sources" (Hughes, 2010, p. 224). This benefit was explicitly shown in the SAFE project with a self-assessment tool in the field of functional thinking (Ruchniewicz & Barzel, 2019). In line with SAFE, the BASE project addresses this gap by developing and researching a digital self-assessment tool (BASE tool) for basic arithmetic knowledge. The material in BASE and SAFE is based on concepts and tasks from the project KOSIMA which led to a research-based textbook to engage students in active learning (Prediger et al. 2021).

Self-assessment

> "Student self-assessment…most generally involves a wide variety of mechanisms and techniques through which students describe…and possibly assign merit or worth to…the qualities of their own learning processes and products" (Panadero et al., 2016, p. 804).

When describing one's learning processes or products, a distinction is made between summative and formative self-assessments. In summative self-assessments, learners evaluate their skills at the end of a lesson, such as giving themselves grades (Tejeiro et al., 2012). Formative self-assessments go beyond this and focus on adapting or changing students' learning processes based on substantive information about their own learning (Andrade, 2019). Summative self-assessments do not have the purpose of deepening understanding and improving performance and related to this, Andrade states: "if there is no opportunity for adjustment and correction, self-assessment is almost pointless" (2019, p. 2). Therefore, when self-assessment is referred to, it should be taken in its formative form.

Various mechanisms and techniques can be used to implement self-assessments. For example, practices can differ based on whether students are given standards to assess themselves (Andrade, 2019). A "checklist-referenced self-assessment" involves providing criteria with which students can evaluate their learning processes or products (Andrade, 2019, p. 3). Checklists could focus on subject-specific or general skills, such as "I can represent multiplications on the number line", or be related to specific characteristics of tasks, for example "One of the two factors in the calculation corresponds to the number of my jumps".

Self-assessments require metacognitive skills, such as the ability to observe and monitor oneself (Zimmermann, 2002). Activating metacognitive skills and taking more ownership can help improve students' academic performance (Brown & Harris, 2013). However, there is a risk that students may incorrectly assess their learning process and draw inaccurate conclusions (Dunning et al., 2004). Therefore, it is important for students to receive feedback from external sources, such as teachers, classmates, or digital assessment tools, in addition to their self-assessment (Ruchniewicz, 2022).

Potential of digital technologies for students' self-assessment

Digital technologies open a variety of options to support self-assessments in mathematics education (Drijvers et al., 2016). Drijvers et al. (2016, p. 12), following Stacey and Wiliam (2013), distinguish two ways of using technology for assessments: (1) assessments *with* technology, which are paper-based and with tools like CAS or geometry software and (2) assessments *through* technology, where technologies are utilized to organize and carry out the entire assessment process (e.g., online diagnosis).

If self-assessment processes are conducted through technology, mathematical concepts and relations can be represented interactively and dynamically to support these processes. By incorporating sample solutions into such interactive and dynamic representations, learners can gain a deeper understanding since learning with sample solutions has proven to be a successful way to gain understanding of the structure and principles of a task (Renkl, 2017) and the presence of explanatory hints which can be requested on demand when students work with sample solutions in a digital learning environment have shown to increase learning (Atkinson & Renkl, 2007).

Automatic analysis of student data can support self-assessment, allowing for immediate feedback (Bokhove & Drijvers, 2012). Following Shute (2008) and Narciss (2008), feedback can be viewed as information provided to students for the purpose of informing them of their current level of learning and inspiring changes in their thinking and behavior. Different types of (digital) feedback can be differentiated (Narciss, 2008, p. 135):

- *Knowledge of result/response*: Students receive feedback only on whether their result was correct or incorrect.
- *Knowledge of the correct results*: Students receive a description or a hint to the correct response for example in the form of a sample solution
- *Knowledge about concepts*: Students receive elaborate information, for instance hints or explanations on subject-matter concepts.

While the design of feedback is always linked to supporting learning processes in relation to the learning objective, its meaning is not solely determined by feedback providers (e.g., students, teachers, digital tools). The extent to which feedback stimulates changes in students' thinking and action depends on how they perceive, interpret and use it (Esterhazy & Damşa, 2019; Rezat, 2021). Therefore, assessing how students use feedback, particularly when transmitted digitally, and how this affects the learning process is important (Rezat, 2021).

In addition, the automatic analysis of student work can not only be used to provide immediate feedback, but also to enable individualized learning paths by automatically allocating suitable follow-up tasks (Stacey & Wiliam, 2013). This can be particularly fruitful within the context of self-assessment because follow up tasks may be allocated not only based on task performance but also on how well the students self-assessed their solution.

THE BASE TOOL

The BASE tool is designed to help students self-assess their arithmetic understanding and gain a deeper understanding of mathematical concepts.

Design principles

Based on the theoretical framework, six design principles emerge for the development of the BASE tool:

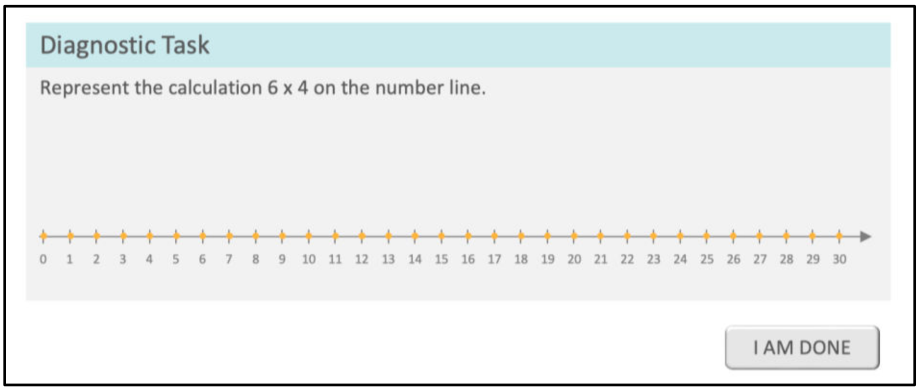
1) *Comprehension oriented tasks* that focus on students' arithmetic understanding
2) *Dynamic and interactive sample solutions* for self-assessment
3) *Self-assessments* guided by content- and task-related criteria
4) *Automatic feedback* provided to students in elaborative and verifying form
5) *Adaptive learning paths* formed based on task solution and self-assessment
6) *Diagnosis guided promotion* by eliciting students' understanding

Structure

In the BASE tool the students first go through a "pre-diagnosis" which comprises three to four diagnostic tasks.

Solving a diagnostic task

Figure 1 shows an example of a diagnostic task, which is part of the pre-diagnosis "Recognizing and Representing Multiplications in Pictures" and requires students to represent a given multiplication by jumps on a number line.



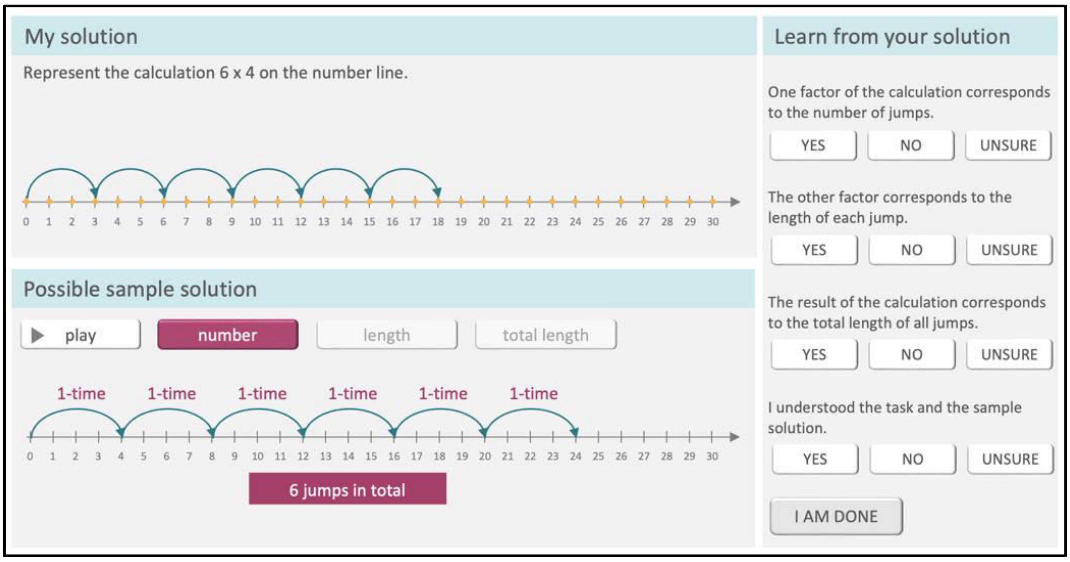
Diagnostic Task

Represent the calculation 6 x 4 on the number line.

Figure 1. Solving a diagnostic task about multiplication

Self-assessment of a diagnostic task

After submitting their solution to the diagnostic task, students are given a self-assessment-checklist (Figure 2 - right) which characterizes a possible solution to the diagnostic task. A statement can be answered "YES" if the students think their solution fulfills the characteristic, "NO" if they do not, and "UNSURE" if they are unsure. To support students in their self-assessment, they are provided with feedback in the form of a sample solution to the task (*Knowledge of the correct results*, Figure 2 - below), along with the self-assessment-checklist. The sample solution allows to dynamically play the jumps. Furthermore, it is possible to display visual and textual cues to highlight and explain certain features (*Knowledge about concepts*). The cues emphasize the concepts addressed in the self-assessment statements.


My solution

Represent the calculation 6 x 4 on the number line.

Possible sample solution

Learn from your solution

One factor of the calculation corresponds to the number of jumps.

The other factor corresponds to the length of each jump.

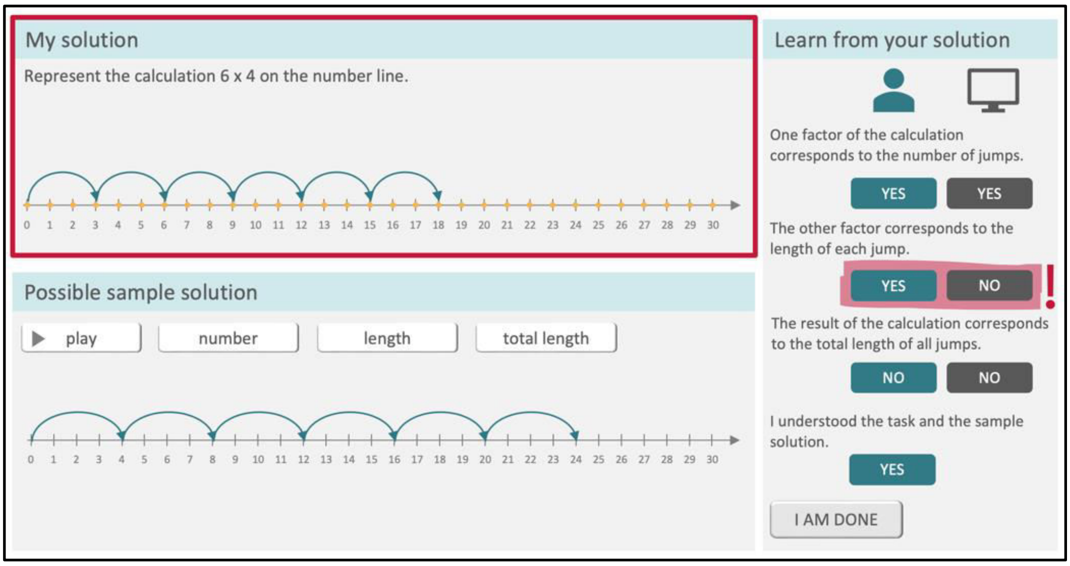
The result of the calculation corresponds to the total length of all jumps.

I understood the task and the sample solution.

Figure 2. Self-assessment of the task with the help of a sample solution

Reflecting on a diagnostic task

After answering the self-assessments statements, students receive feedback on their task solution (highlighted solution, top left in Figure 3) and self-assessment (highlighted wrong-self assessments, right in Figure 3), indicating if they were correct or incorrect (*Knowledge of result/response*). The feedback can be used to reflect on the diagnostic task.


My solution

Represent the calculation 6 x 4 on the number line.

Possible sample solution

Learn from your solution

One factor of the calculation corresponds to the number of jumps.

The other factor corresponds to the length of each jump.

The result of the calculation corresponds to the total length of all jumps.

I understood the task and the sample solution.

Figure 3. Reflecting on the task with the help of feedback on task solution and self-assessment

Once all diagnostic tasks of a pre-diagnosis are done, the BASE tool automatically assigns exercises. The selection of the exercises depends on one hand on the correctness of the solutions of the diagnostic tasks and on the other hand on the correctness of the students' self-assessment. After completing the exercises, the students take a "post-diagnosis" which comprises the same diagnostic tasks as the pre-diagnosis but with different numerical values. A complete overview of the structure of the BASE tool is given in Figure 4.

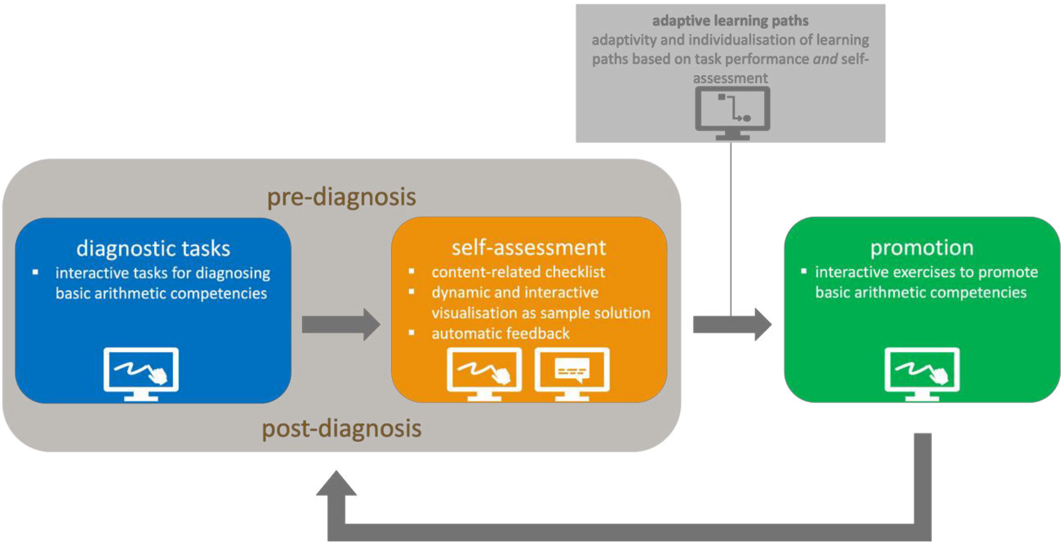


Figure 4. Structure of the BASE tool

RESEARCH QUESTIONS AND METHODOLOGY

Students using the BASE tool formulate feedback to themselves and additionally receive external feedback in the form of dynamic and interactive sample solutions and verifying feedback on the accuracy of their task solution and self-assessment.

This raises the following question:

How does digital feedback

a) as elaborated feedback in the form of dynamic and interactive sample solutions and
b) as verifying feedback on task solution and self-assessment

affect learners' multiplicative understanding and metacognition in the context of self-assessment processes?

To answer these research questions, we are currently conducting a qualitative study. For this we videotaped 12 students working on the diagnostic task described in the last section. In the following we outline the theoretical framework that we have developed in order to analyze the data. One way to analyze the impact of feedback on students' understanding is the theory of instrumental genesis and the concept of scheme as shown by Rezat (2021).

Conceptualizing feedback as an artifact

Rezat (2021, p. 1436) conceptualizes feedback as an artifact that can assist students in performing and reflecting on their work ultimately supporting the development and conceptual understanding (Figure 5). This concept of using artifacts to solve a problem or task, where we will refer to the problem or task as the "object" in the following, was first referred to as the "instrumental act" by psychologist L. S. Vygotsky: “[I]n the instrumental act a new middle term is inserted between the object and the mental operation directed at it: the psychological tool [= artifact], which becomes the structural center or focus” (Vygotsky, 1997, p. 87). Using an artifact to solve a problem requires that the subject is aware of the artifact’s existence, as well as its purpose and how it can be used. Utilization schemes - the schemes associated with using the artifact - must be developed in order to make the artifact an effective instrument in the subject’s actions (Drijvers, 2002; Rabardel, 2002). An important component of these schemes is the notion of “operational invariants”, which represent the implicit knowledge of schemes (Rezat, 2021, p. 1435). Operational invariants are composed of *concepts-in-action* and *theorems-in-action*, wherein concepts-in-action refer to mathematical objects (e.g., factors, product tick marks on a number line) that are considered relevant or irrelevant by the subject, and theorems-in-action are statements about the mathematical objects that the subject believes to be true but may not be mathematically accurate (Vergnaud, 2009, p. 88).

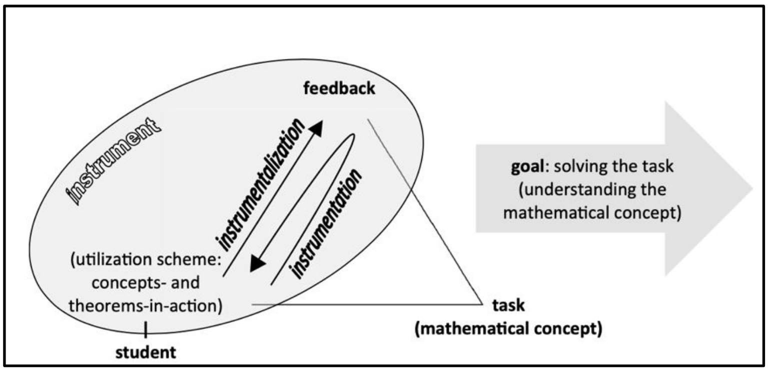


Figure 5. Theoretical framework of Rezat (2021, p. 1436)

The acquisition and further development of utilization schemes in relation to the tool is called *instrumentation*. By *instrumentalization,* he describes the discovery and use of characteristics and properties of the tool. The process of instrumentalization and instrumentation is summarized as *instrumental genesis* (Rabardel, 2002).

An integrated framework to investigate changing forms of feedback in time

One limitation of the instrumental genesis framework in general is that it is limited to a static artifact and one object. However, when students solve the diagnostic tasks and perform the self-assessment in the BASE tool, they encounter different forms of feedback that change over time. Furthermore, the object changes. In the following we will explain how we take up this fact in the theoretical framework and further develop Rezat's theory model (Figure 5) to address the dynamic of feedback and the object.

While solving the multiplication task (Figure 1), the pre-existing knowledge of the students in the form of concepts- and theorems-in-action should be explored (Figure 6, first small triangle).

After completing their task, students should assess their solution with a self-assessment-checklist (see Figure 2). The self-assessment can be defined as the object of the student’s current action (Figure 6, second small triangle). Students are provided with elaborated feedback as an interactive, dynamic sample solution to support their self-assessment. So, the sample solution serves as an artifact in this case, and it will be analyzed which functions are attributed to the sample solution, which elements are used and how the attribution and use influences the previously elaborated concepts- and theorems-in-action. Assuming instrumental genesis will be accompanied by metacognitive activities, these will be integrated into the analysis.

In the last step of a diagnostic task, students should look back and reflect on their solution and self-assessment (see Figure 3). To support this, verifying feedback is provided as an artifact (see Figure 6, third small triangle). It will be analyzed how students understand and use this feedback and the impact it has on their metacognition and multiplicative understanding.

Statements about the stability of the last elaborated concepts- and theorems in action can be made possible by having each student process a second analogous task which is part of the post-diagnosis. This will allow for a detailed analysis of the learning process and how it is influenced using the BASE tool and the feedback it provides over time. The results will help to understand how students perceive, interpret, and use the feedback provided within the BASE tool and how that affects their learning.

By analyzing the effects of feedback, its conditions for success and difficulties in the context of self-assessments are to be worked out in the long term.

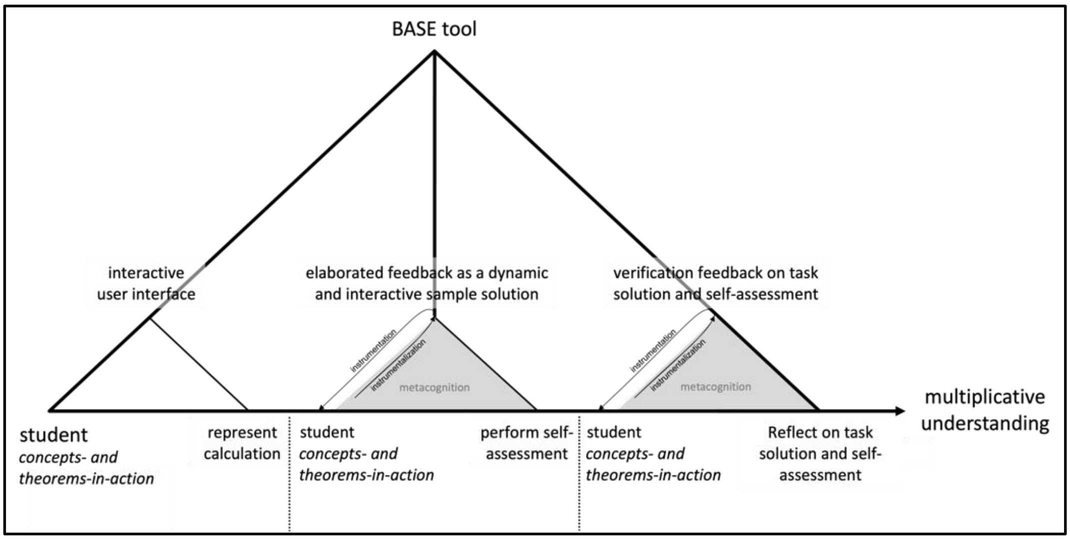


Figure 6. Theoretical framework for tool research

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