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A case study of a formative assessment practice and the effects on students' self-regulated learning

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ABSTRACT

The study investigates one mathematics teacher's implementation of formative assessment and its effects on students' self-regulated learning (SRL). A questionnaire administered before and after the eight-month long intervention shows a significant effect, compared to two control classes, on students' motivational beliefs involved in SRL. Qualitative data shows a notable enhancement of the students' SRL behavior in the classroom. Analysis of the teacher's implemented formative assessment shows a practice integrating several aspects of formative assessment, and provides empirical evidence of what formative assessment with large effects on students' SRL may look like and how it fits with models of SRL development.

1. Introduction

1.1. Self-regulated learning

Self-regulated learning (SRL) is associated with academic achievement (e.g., Brown & Hirschfield, 2007; Panadero, 2017; Richardson, Abraham, & Bond, 2012; Timperley & Parr, 2009) and is considered a cornerstone of life-long learning (Gielen, Dochy, Onghena, Struyven, & Smeets, 2011; Lüftenegger et al., 2012). Furthermore, SRL skills are identified as "necessary for personal fulfilment, active citizenship, social cohesion and employability" (European Commission, 2007, p. 3) and students' SRL skills are considered essential to making high-quality teaching in large student groups possible (Williams et al., 2011). Based on the wide range of research pointing to the importance of SRL, it could be described as a key competence the education system needs to strive to achieve.

Self-regulated learning involves metacognitive, motivational, and behavioral processes and beliefs in a proactive regulation of the learning process (Zimmerman, 2008). There are several models of SRL that share similar elements and processes (Chen & Bonner, 2020). In the model by Zimmerman, SRL processes and accompanying beliefs fall into three cyclical phases: forethought, performance or volitional control, and self-reflection (Zimmerman, 2000). The forethought phase refers to processes and beliefs before efforts to learn, the performance phase includes processes during the implementation of effort and the self-reflection phase involves processes after each learning effort. There are two main classes of *forethought phase processes*: *task analysis* and *self-motivation*. Task analysis includes *goal setting* and *strategic planning*. Self-motivation stems from beliefs about learning. For example, *self-efficacy beliefs* refer to a student's confidence in succeeding with learning or solving a task, and perceived autonomy involves perceiving the freedom to carry out the self-regulated learning processes. *The performance phase processes* fall into two major categories: self-control and self-observation. *Self-control processes* refer to the deployment of methods or strategies that help the students focus on the task. Through self-observation processes, the students monitor the learning process. Thus, in the performance phase, they discern patterns in their behavior and the results of this behavior so they can change their learning efforts when necessary. The *self-reflection phase processes include* self-evaluation of the success of a performance and attributing the outcome to a cause. This view of self-regulation is cyclical in that self-reflections from prior efforts to learn affect subsequent forethought processes.

1.2. Development of SRL-skills

The development of SRL-skills in the three phases and how they may be supported can be described in a series of four developmental levels: observation, emulation, self-control and self-regulation (Zimmerman,

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2000). At the observation level (Level 1), a student can induce the major features of the skill by observing a proficient model, such as the teacher. To support student development of SRL skills, the teacher can show the students how the skill can be performed and clarify why, when and how to use the skill. At the emulation level (Level 2), the student can perform the skill in a way that approximates the general strategic form of the model, for example, the type of self-generated metacognitive questions asked during task-solving rather than the exact wording of such questions. To attain this level, it is generally advantageous to also practice the skill (and reflect over this practice) and receive guidance, feedback and social reinforcement from the teacher.

Attainment of self-regulatory skills at the self-control level (Level 3) occurs when the students master the use of a skill in structured settings outside the presence of a model. At this level, the students' use of a skill depends on representational standards of a model performance (e.g., covert images or verbal recollections of a teacher's performance) rather than an overt/direct social referent. In order to be able to use a skill on one's own, it is often necessary to deliberately practice the skill independently. The teacher can structure such a practice and then reflect over the processes together with the students to enhance performance and self-observation. Finally, the self-regulation level of an SRL skill (Level 4) is achieved when learners can systematically adapt their use of task strategies to changing personal and contextual conditions and make adjustments based on outcomes. The teacher may support the development of such skills by providing students with opportunities and expectations to practice these skills and support their self-evaluation of the practices.

1.3. Formative assessment

A type of classroom practice that has been suggested as a promising (e.g. Andrade & Brookhart, 2016; Black & Wiliam, 1998), and even particularly well suited (Clark, 2012), way to support students in becoming self-regulated learners is formative assessment. When putting formative assessment into practice, the teacher gathers evidence of the students' learning, and based on the identified learning needs, adapts instruction or feedback to meet these needs. The students may also be the agents of these formative assessment practices through peer assessment and self-assessment, including feedback to their peers or themselves. The teacher's role in accomplishing a formative assessment practice in which the students are active agents in the core formative assessment processes is to help students become motivated and proficient in carrying out these processes. In addition, in order for formative assessment practices to be most effective, the teacher may work together with the students to achieve a mutual understanding of the learning goals and establish criteria for attainment of these goals on different levels (Black & Wiliam, 2009).

1.4. Formative assessment as support for the development of self-regulated learning

Theoretical accounts of how formative assessment may drive the acquisition of self-regulated learning strategies have been formed (e.g., Clark, 2012; Cizek, Bennett, & Andrade, 2019; Nicol & McFarlane-Dick, 2006), and one model used for these accounts is the SRL model created by Zimmerman (2000). For example, Panadero and Broadbent (2018) used this model to argue that formative assessment, and self-assessment and peer-assessment in particular, may enhance self-regulated learning. Chen and Bonner (2020) built on the Zimmerman model and proposed a framework, CA:SRL, which involves classroom assessment and SRL, and noted that formative assessment may provide students with opportunities to develop their SRL skills in all phases of SRL. Andrade and Brookhart (2020) refer to Allal (2011), who notes that students' SRL processes in educational contexts are often influenced by other students as well as other sources, such as teachers, curriculum materials and assessment instruments. Thus, self-regulated learning is often co-regulated. Andrade and Brookhart used this concept of co-regulation to expand on a model of SRL by Pintrich and Zusho (2002) and described how classroom assessment and formative assessment may influence the development of co-regulation and self-regulated learning. Nicol and McFarlane-Dick (2006) proposed a model and seven principles for how formative assessment processes can support the development of students' self-regulated learning. These principles are (not in the same order as in Nicol and McFarlane-Dick, 2006):

(Principle 1, P1) Facilitate a shared understanding of the learning goals between the students and the teacher. (P2) Gather frequent information about the students' learning. (P3) Teacher feedback that targets the students' learning needs. (P4) Create structured opportunities for students to practice self-regulation skills. Opportunities for practicing these skills may, for example, be created by structuring self-assessment activities. (P5) Provide students with opportunities to discuss the teacher's feedback and to be engaged in peer dialogue based on peer assessment and peer feedback in relation to criteria and standards. (P6) Provide feedback that supports motivational beliefs that drive self-regulation processes. (P7) Provide opportunities to close the gap between students' current and desired performance.

In addition to theoretical accounts of how formative assessment may support the development of students' self-regulated learning, some studies have provided empirical examples of how formative assessment may influence an individual student's use of SRL skills (e.g., Hawe & Dixon, 2017) as well as how different aspects of formative assessment may be associated with different aspects of students' SRL behavior (e.g., Baas, Castelijns, Vermeulen, Martens, & Segers, 2015). However, Dinsmore and Wilson (2016) showed that active participation in formative assessment processes (e.g., self-assessment, peer assessment and opportunities to use teacher feedback) does not always improve SRL practices. Indeed, Harris, Brown, and Dargusch (2018) found several forms of maladaptive student actions during formative assessment practices. In addition, research on the effects of interventions using teaching designs conceptualized as formative assessment on students' SRL has largely been conducted in the context of higher education, and intervention studies that focus on students in K-12 are relatively scarce. A database search in ERIC, APA PsychInfo, Academic Search Premier and SCOPUS [using the Boolean search command ("formative assessment" OR "assessment for learning") AND ("self-reg*") in the title, abstract and keywords] returned 200 journal articles. Only 7 of these were empirical studies that examined the effects of formative assessment on the self-regulated learning of K-12 students.

In a 3 h intervention with 16-year old geography students, Panadero, Tapia & Huertas (2012) found a statistically significant effect on self-efficacy in the students who used a self-assessment tool combined with feedback, but no effect was found for the use of self-assessment alone. In addition, they found an effect from the self-assessment intervention on students' self-regulation behavior when self-regulation behavior was measured by thinking-aloud protocols but not when it was measured by a student questionnaire. During three writing assignments over 27 weeks, Meusen-Beekman, Brinke, and Boshuizen (2016) investigated the effects of classroom practice that integrated several aspects of formative assessment and were focused either on self-assessment or peer assessment. They did not find significant effects from these formative assessment practices on self-efficacy in sixth graders, but they did find significant effects on both intrinsic motivation and self-regulated behavior. In a 9-week intervention with mathematics students in grades 4–6, Smit, Bachmann, Blum, Birri, and Hess (2017) found positive effects from the use of rubrics in self-assessment and peer assessment on the students' self-efficacy and SRL behavior. Wang (2011) found positive effects on students' SRL skills in students who used peer assessment based on their answers to science tests. Baas et al. (2015), on the other hand, found that elementary students' use of portfolios to track where they were in their learning only predicted the students' goal-setting and the planning parts of SRL, while the degree of support teachers provided to students as they took the next steps in their learning

(e.g., through scaffolding) predicted the use of SRL skills strategy and reflection on learning (but not product evaluation). Laxdal, Mjåtveit, Leibinger, Haugen, and Giske (2019), in a self-report study of upper-secondary students, found that the students' perceptions of teachers' formative assessment practice predicted their self-regulatory behavior. Finally, Lam (2013) found modest effects on some aspects of students' (age 7–8) SRL in an intervention where students prepared for a test by formatively using tests that were ordinarily used for summative purposes.

Thus, In the K-12 context, studies on the effects of different aspects of formative assessment practices on students' SRL have shown mixed results, both when it comes to the effects on motivational beliefs that are important for the self-regulation processes and effects on SRL behavior. However, in most studies on the effects of formative assessment on SRL, formative assessment is operationalized as self-assessment or peer assessment. Indeed, in only one of the studies (Meusen-Beekman et al., 2016) is formative assessment carried out on a daily basis over an extended period of time in a format where the teacher continuously identifies the students' learning needs and adapts instruction accordingly as well as providing support for the students to act as proactive agents in the formative assessment practices through self-assessment and peer assessment processes. However, while the study by Meusen-Beekman et al. (2016) included information provided to the teachers on how to conduct the intervention, it was not within the scope of the study to present more detailed descriptions of how these practices were actually carried out by the teachers.

Moreover, in addition to drawing conclusions about the effects of formative assessment on students' beliefs based on self-reports, conclusions about the effects of formative assessment on the development of students' SRL skills and behavior have also mainly been based on students' self-reports. The only studies we have found on the effects of formative assessment interventions on the SRL beliefs and practice of K-12 students that measure SRL in ways other than self-reports were the studies conducted by Lam (2013) and Panadero, Tapia, and Huertas (2012). Indeed, recent research reviews have called for experimental and quasi-experimental studies to investigate the effects of formative assessment interventions on students' SRL (McLaughlin & Yan, 2017; Panadero, Andrade, & Brookhart, 2018) and for complementing self-reports with other measurements of SRL (Panadero et al., 2018). McLaughlin and Yan (2017) also emphasized the need for studies that not only look at the effects on students' self-regulatory processes triggered by feedback from teachers or peers but also the effects of formative assessment on true SRL where students independently and continuously monitor, evaluate and adapt their learning to attain their learning goals during their daily classroom practice.

To supplement the existing body of research on the effects of formative assessment on students' SRL, the current study investigates the effects on students' self-regulated learning from a formative assessment practice carried out as a daily classroom practice by a grade-7 mathematics teacher for 8 months. This practice was intended to include both teacher-centered aspects of formative assessment and teacher support so that students could be proactive agents in the formative assessment processes. Self-reported data about the formative assessment practice and students' self-regulated learning behavior is complemented by classroom observations. Students' self-reported motivational beliefs are compared to those in two control classes. Emphasis is also given to daily SRL practices that are initiated and sustained by the students themselves rather than being prompted by the teacher.

2. Research questions

RQ1) Does the formative assessment practice implemented by the teacher have an effect on the students' perceived autonomy?

RQ2) Does the formative assessment practice implemented by the teacher have an effect on the students' self-efficacy in their learning?

RQ3) How does the students' SRL behavior change between the beginning and end of the period formative assessment is implemented?

RQ4) What are the characteristics of the implemented formative assessment practice that have an impact on the students' self-regulated learning?

3. Methods

3.1. Participants

The teacher who participated in the intervention of the present study had worked at another school the previous year as one of two mathematics teachers, during a time when all teachers at the school participated in a formative assessment professional development program lasting two and a half years. The three authors were involved in this professional development program that was led by the third author. Both mathematics teachers were invited to participate in the study, but only one accepted the invitation. The teacher taught one seventh grade mathematics class in his new school with three seventh grade classes. Two of his colleagues taught the other two classes. All three teachers were experienced teachers (>10 years). The two colleagues had not participated in the professional development and expressed that they had not attempted to implement a formative assessment practice. The two teachers continued to teach according to the methods all three teachers had used before the intervention. This traditional approach to teaching is characterized by whole-class lectures followed by seatwork where the teacher helps the students when they encounter difficulties solving tasks. The class of the teacher who implemented a formative assessment practice constituted the intervention class, and the two parallel mathematics classes taught by his colleagues were chosen as control classes.

The participating students were 13–14 years of age and from different social and cultural backgrounds. The number of students in the intervention class was 18, and 18 and 19 in the two control groups, respectively. Fourteen students in the intervention class (9 female, 5 male) and nine students in each control class (5 female, 4 male and 4 female, 5 male, respectively) agreed to participate and provided signed consent forms from their parents. The relatively low number of participants in the control classes was largely due to logistical difficulties in getting the consent forms back from the students' parents.

3.2. Procedure

The teacher, participating in the present study started the school year in August with a new class. One month later, he started the intervention where a formative assessment practice was implemented throughout the rest of the school year with the aim of both enhancing the students' mathematical proficiency and their development of self-regulated learning. Implementation was based on experiences gained over the schoolyear and what the teacher learned during participation in the professional development program. The intervention was designed and carried out by the teacher alone. The researchers collected data about the intervention and its effects (see Section 3.3 below), but they were not involved in any part of the intervention. The teacher taught mathematics three times a week; during the intervention, these lessons were designed as follows: In the first lesson, *Teacher-math*, the mathematical content was introduced. In the second lesson, *Calculating-math*, the students were engaged in task solving. The third lesson, *Test-math,* concerned goal setting and evaluation of the students' achievements.

The effects of the teacher's formative assessment practice on students' perceived autonomy (RQ1) and self-efficacy (RQ2) were investigated through a questionnaire administered to the students at the

beginning and the end of the intervention period. Since students' motivational beliefs vary over time (Winberg, Hofverberg, & Lindfors, 2018), students in the school's two parallel classes functioned as control groups. The effect of the formative assessment implementation on the students' self-regulated learning behavior (RQ3) was investigated using classroom observations and interviews. An analysis of the characteristics of the formative assessment practice underlying the effects on students' beliefs and behavior (RQ4) was performed based on classroom observations, teacher logs and interviews.

3.3. Data collection

3.3.1. Quantitative data

Since motivational beliefs are part of self-regulated learning and instigate and sustain learning behavior, such beliefs were included in the study. Students' perceived autonomy and their self-efficacy beliefs complement each other. Students with high perceived autonomy think they have the opportunity to influence how to learn, and students with high self-efficacy believe they can successfully do so. Complementing the analysis of the students' SRL behavior (Section 3.3.2) with an analysis of motivational beliefs that influence this behavior may provide further understanding of the development of self-regulated learning. A web questionnaire including items aimed to capture students' perceived autonomy and self-efficacy beliefs was used to collect data for RQ1&2. Each teacher devoted lesson time so the students had an opportunity to answer the questionnaire both before the intervention early in October and after the intervention in April. The questionnaire items are given in Table 1:

All items were answered by choosing the extent to which one agreed with the statements on a scale from 1 (not at all) to 7 (fully agree). The items are adaptations of previously used questionnaire items (Deci & Ryan, 2000; Gagne, 2003; Williams & Deci, 1996). Cronbach's alpha for each set of items in our study in spring/fall was .77/.81 for perceived autonomy and .80/.86 for self-efficacy, indicating acceptable to good internal consistency reliability. The mean of the items connected to a construct at each time point was used as a representation of students' perceived autonomy and self-efficacy at that particular time point. Since this was a lengthy intervention and the teacher aimed to enhance students' learning and self-regulation of learning within mathematics, which are broad goals, the items used to capture each construct connected to general self-efficacy (regarding learning mathematics) and perceived autonomy (focusing on the freedom to carry out the self-regulation process). The use of general measures may come with a loss in predictive power (Bandura, 1997), which in our case could mean a reduced likelihood of observing true effects from the intervention. However, in an authentic school setting where a wide range of different mathematics skills are to be learned under different conditions, it seems more likely that specific measures run the risk of becoming atypical.

3.3.2. Qualitative data

The collection of data in order to make conclusions about the students' self-regulated learning behavior in the classroom (RQ3) and the teacher's practice (RQ4) did not include a questionnaire, but focused on teacher logs and observations accompanied by interviews. The reasons for this choice include the wish to obtain more direct evidence of the students' and teacher's classroom practice. To answer these research questions, four sources of data were used: teacher logs, teacher interviews, classroom observations and ten student interviews. The logbook was digital, and after each lesson, the teacher was asked to describe his choice of learning activities, the aim of the activity and his observation of why the aim was reached or not. The teacher was interviewed twice, in the beginning and at the end of the intervention. During the interviews, the teacher was asked to provide a detailed description of the activities he implemented in his classroom and his experience after implementing these. Each interview was 1.5 h in length, recorded and then transcribed. During the intervention, the first author observed eight lessons, 60 min each. The observer took notes, capturing classroom activities and the teacher-student interactions during these activities. The student interviews focused on the most frequently occurring activities, as described in the teacher logbook (see Section 4.4), and asked the students to describe their experiences within each of these activities. These multiple sources of quantitative data (the questionnaires) and qualitative data (i.e., the teacher's and researcher's judgment of classroom activities) and the students' comments and reported experiences within these activities will be used for triangulation to reassure the validity and reliability of the study.

Table 1
Questionnaire items.

Perceived autonomy	Self-efficacy
I feel that if I want to, I have the possibility to influence what we do during lessons	I am sure I have the ability to understand the content in this subject
I believe that my teacher is interested in what I would like us to do during the lessons	I believe I can manage to learn the content in this subject
My teacher gives me opportunities to make own choices during the lessons	I feel that I can do well in this subject
My teacher gives me good opportunities to decide what I need to do to learn mathematics	I have the opportunity to reach my goals in this subject

3.4. Method of analysis

To investigate the effects of the implemented formative assessment practice on the students' perceived autonomy and self-efficacy (RQ1 and RQ2), mean differences in the responses to the questionnaire items pertaining to these constructs between fall and spring were calculated for students in the intervention class and the control classes. The differences between fall and spring for the intervention class were compared with each of the control classes. Welch's *t*-test was performed to test for statistical significance of the differences, and Hedges' g was calculated as a measure of the size of the effects.

Changes in the students' SRL practice (RQ3) were identified through an analysis of observation data and teacher and student interviews. This was done by noting students' actions, observed or described, that could be identified as any of the skills described in Zimmerman's three self-regulation phases (Forethought, Performance and Self-reflection). These skills were further categorized according to Zimmerman's four proficiency levels of regulatory skills (Observation, Emulation, Self-control or Self-regulation). For example, if the students were observed to choose learning goals that followed the teacher's instructions, that skill was identified as goal setting in the *Forethought phase* and categorized as performed at *Emulation level*. The identified skills and level of self-regulation proficiency after the intervention was compared to the identified skills and levels before the intervention.

To describe the characteristics of the formative assessment interventions implemented by the teacher, which resulted in the effects identified in RQ1−3, observations, logbooks, and interview data were analyzed to identify the learning activities regularly implemented to enhance students' self-regulated learning. The students' experiences of these activities, as expressed in the interviews, were added to the data set. As a second step, the identified activities were described in relation to the phases of self-regulation: Forethought, Performance and Self-reflection (Zimmerman, 2008). The third step was to use the definition described by Black and Wiliam (2009) to identify aspects of formative assessment in these activities. Practices such as: setting learning goals, gathering information about learning progress, the use of this information to provide feedback or adapt learning activities to the students identified learning needs, peer assessment and peer feedback, and self-assessment with subsequent actions to attain learning goals were noted. Finally, Zimmerman's model of self-regulated learning (2000) and Nicol &Macfarlane-Dick's (2006) seven principles were used

in the analysis of how the characteristics of the teacher's formative assessment practice may have affected the students' self-regulated learning.

4. Findings

4.1. The effect of the formative assessment practice on students' perceived autonomy (RQ1) and self-efficacy (RQ2)

The graph in Fig. 1 and the numbers in Table 2 show that the students' perceived autonomy increased markedly from fall to spring in the intervention class while it decreased in control class A and increased only slightly in control class B. Despite the fact that students in the intervention class, on average, showed a lower perceived autonomy than students in either of the control classes in the fall, the students' perceived autonomy in the spring was, on average, higher in the intervention class than in both control classes.

The size of the effect of the formative assessment implementation on students' perceived autonomy, estimated by comparing the difference between fall and spring in the intervention class with the difference in each of the control classes A and B, was very large (Hedges' $g = 1.72$ and 2.63 respectively), and each between-group comparison of change was statistically significant ($t(12.690) = 3.690$, $p = .003$; $t(18.765) = 4.744$, $p = .001$).

Fig. 2 and Table 3 show increases in students' self-efficacy from fall to spring in the intervention class while it decreased in both control classes.

The size of the effect of the intervention on students' self-efficacy, estimated by comparing the difference between fall and spring in the intervention class with the difference in each of the control classes A and B, was very large (Hedges' $g = 1.11$ and 1.25 respectively) and each between group comparison of change was statistically significant ($t(18.045) = 3.684$, $p = .002$; $t(20.644) = 3{,}131$, $p = .005$).

The identified changes in the students' perceived autonomy from the questionnaire data (Table 2) were also observed in the qualitative data. The students were invited and took the opportunity to make their own choices about what they would learn (e.g., setting learning goals), what to practice (e.g., choosing worksheets), and to choose useful learning strategies (e.g., using their inner voice) (see Section 4.3.2 for a description of activities and strategies presented to the students by the teacher). Furthermore, the positive impact on students' self-efficacy seen in the questionnaire data (see Table 3) is mirrored in the students' interviews but also in the teacher's and researcher's observations of increased confidence among the students in their choice of worksheets and constructing their own test tasks aiming for learning, choice of task solving strategies, and increased time spent working on tasks before asking the teacher for help.

The observer noted that the increase with respect to perceived autonomy preceded the students' expressions of self-efficacy. The teacher initiated the intervention by encouraging the students to become more autonomous by implementing a series of activities and strategies (see Section 4.3.2). With few exceptions, the students engaged in these activities from the very start and developed their proficiency within these skills during the intervention. Their increase in self-efficacy, identified, for example, as a shift from making statements such as "I don't understand anything" to asking mathematically anchored questions, and their tendency to choose to engage in difficult tasks, were not, however, observed in the beginning of the intervention. These changes came more gradually, and it was also noted that the change in perceived autonomy and self-efficacy were more prominent among the low- and medium-achieving students.

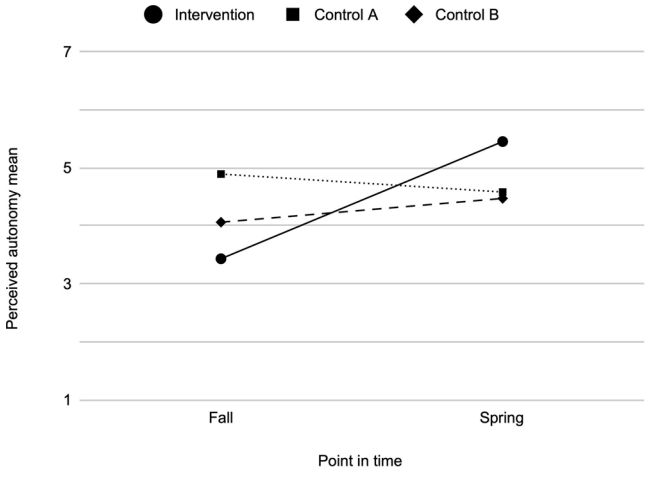

Fig. 1. Changes in Students' Perceived Autonomy.

Table 2
Mean Scores and Standard Deviations for Students' Perceived Autonomy.

		Preintervention (Fall)		Postintervention (Spring)		Difference	
Group	N[a]	Mean	SD	Mean	SD	Mean	SD
Intervention	14	3.43	1.14	5.45	.78	2.02	1.12
Control A	9	4.89	1.64	4.58	1.70	−.31	1.66
Control B	9	4.06	1.35	4.47	1.33	.42	.47

Note. The students in each group (Intervention, Control A and Control B) are the same in the pre-measurement (in fall) and the post-measurement (in spring).

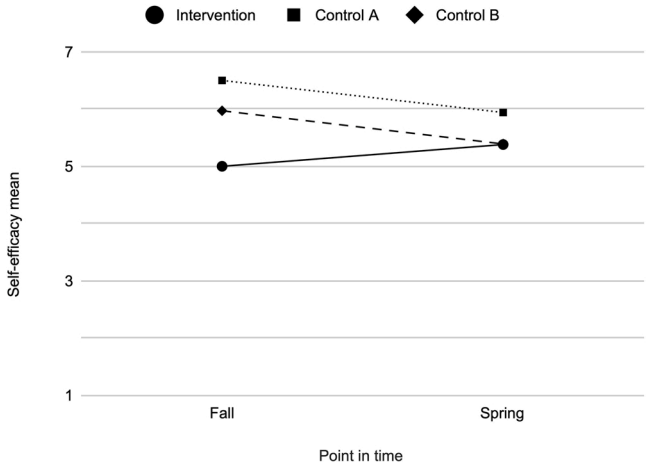

Fig. 2. Changes in Students' Self-efficacy.

Table 3
Mean Scores and Standard Deviations for Students' Self-efficacy.

		Preintervention (Fall)		Postintervention (Spring)		Difference	
Group	N[a]	Mean	SD	Mean	SD	Mean	SD
Intervention	14	5.00	1.11	5.38	.81	.38	.85
Control A	9	6.50	.59	5.94	.68	−.56	.85
Control B	9	5.97	.74	5.39	1.09	−.58	.61

Note. The students in each group (Intervention, Control A and Control B) are the same in the pre-measurement (in fall) and the post-measurement (in spring).

4.2. The change in students' SRL behavior (RQ3)

Observations before the intervention showed a classroom practice where few students initiated learning activities such as task-solving unless the teacher called on them. The students frequently asked the teacher for help, using statements like: "I don't understand anything," "I

forgot how to do it." These observations are in line with the teacher's narratives, which highlighted the fact that his students lacked strategies to initiate their work and manage the problems they encounter "They do not have the self-confidence to try to solve a task without knowing the correct method. They ask before even trying." The teacher further described that his students rarely tried to identify where they needed help or to look for opportunities to practice. The teacher gave examples by discussing the diagnostic tests often used in schools to gather information about students' performances: "Students take diagnostics test merely for the benefit of the teacher. They never bother with their results. They hold me responsible for acting on the result, telling them what to do." There were furthermore few initiatives for goal setting or strategic planning in Zimmerman's forethought phase. The students showed a general deficit of self-motivation and rarely carried out self-control processes to focus on the learning tasks in the performance phase nor initiated evaluations of learning in the self-reflection phase. With few exceptions, the students did not practice self-regulation skills at any of Zimmerman's (2000) developmental levels.

In contrast, observations at the end of the intervention showed a classroom practice where most students initiated learning activities, such as task-solving, without the teacher asking them. Furthermore, there were considerably fewer students asking for help, and the students' questions had generally changed from statements like: "I do not understand anything" to questions like: "I want to practice equations with x on the both sides, do you have any worksheets I can use?", "I did not understand why you can't add x and y and get the answer xy, could you explain again," The teacher described similar experiences: "Now they have the skills to start working without me even being in the classroom. They know how to relate their learning goals to their results on practice tests and to choose useful strategies to strive for these goals, such as selecting suitable worksheets to learn something specific, asking for specific help and so forth." Indeed, in addition to choosing between worksheets provided to them, observations identified that students even asked for worksheets that had not already been provided so they can practice specific tasks. Moreover, the students had developed the skills to approach tasks using different task-solving strategies. As some of the students expressed in the interview: "I tell myself to read the task and start all over again.", "I decided to draw and write stuff before asking, and poof, I realized that I didn't need help after all."

These changes are interpreted as increased use of and proficiency in self-regulation among the students. The students set learning goals and took the initiative to choose worksheets accordingly in the forethought phase. In the interview, one of the students expressed his thinking in this process as "I ask myself what I need to practice." They entered the performance phase by initiating task-solving without the teacher prompting them. They had greater focus when working with their tasks by using self-control processes in this phase. An example is the use of an 'Inner voice,' which was something they learned in the classroom practice (see Section 4.3.1) in which the students said to themselves, for example, "I tell myself to concentrate" and "I like to borrow my teacher's inner voice to learn how to solve difficult tasks." Finally, even though the activities in the Self-reflection phase were initiated by the teacher, the students were able to evaluate their performance and identify what they needed to learn and/or practice to reach their learning goals. Hence, the comparison of the students' behavior before and after the intervention showed a significant change with greater levels of Self-control and Self-regulation in all of Zimmerman's Self-regulating phases.

4.3. Characteristics of the formative assessment practice (RQ4)

In the following section, the classroom activities, identified as regularly occurring and implemented to support students' self-regulated learning of mathematics, are presented (4.3.1). Thereafter, the identified activities are presented and further analyzed using Zimmerman's phases of self-regulation (4.3.2). In Section 4.3.3, an analysis of how the characteristics of this formative assessment practice may have supported the development of students' self-regulated learning is presented.

4.3.1. Identifying activities implemented to support students' self-regulated learning

Three activities that were repeatedly used and implemented to enhance students' self-regulation skills were identified and categorized as: 'Learning Zones', the 'Inner voice,' and the 'Invisible cloak.' The use of 'Learning Zones' and the 'Inner Voice' were integrated parts of their daily work, and the 'Invisible cloak' was used regularly, but not during every lesson. Another three activities: 'Worksheets,' 'Constructing test-tasks,' and 'Practice tests' were implemented to support students' learning of mathematics while also practicing self-regulation. The teacher provided multiple 'Worksheets' that the students could choose from, which differed in terms of content and difficulty. These worksheets were present in all lessons; however, they were mainly used during *Calculating-math* lessons. 'Constructing Test-tasks,' 'Practice tests,' or other activities aimed at supporting students in setting their goals or evaluating their achievements were frequently used during *Test-math* lessons. The teacher also asked the students to answer questions on mini whiteboards, which made the answers from all students easily visible for him, and used 'one-task-tests' to gather information about *all* of the students' understanding of the mathematics material introduced during *Teacher-math*. The quick questions asked using mini whiteboards during lessons mainly concerned basic mathematics that the students were expected to know, such as: solve the equation $5x+3=13$, simplify the polynomial $4x+4-2x+2$ etc., while the 'one-task-tests,' usually given at the end of a lesson, aimed to check both basic mathematics skills and the students' ability to solve more challenging tasks (i.e. Zone 2 tasks, see 4.3.2). One example of the latter: Construct an equation that when solved gives the answer $x=7$. Below, the above described activities will be presented and further analyzed.

4.3.2. Presentation of activities aimed at supporting students' self-regulated learning of mathematics

The six activities identified above were examined in relation to the phases of self-regulation: Forethought, Performance and Self-reflection (Zimmerman, 2008). The identified activities, as part of a self-regulation teaching design, are presented in the following.

4.3.2.1. Learning zones. The teacher described how he presented learning as a process of being in and moving between three zones. Zone 1 represents a state when things are difficult and may be out of reach without an (additional) introduction from the teacher. Zone 2 is when something is perceived as challenging but within reach. Zone 3 is when a specific piece of knowledge has already been acquired and the student may spend time practicing. The teacher pointed out to his students that in order to learn something new, they needed to deal with the mathematics material in Zone 2. The teacher described that in the 'Forethought Phase,' the students need to identify and choose learning goals that they believed fell into Zone 2. In the 'Performance Phase,' the students need strategies for self-control, self-observation and task-solving strategies to be able to remain in Zone 2. In the 'Self-Reflection Phase,' the students need to evaluate their learning and attribute outcomes to a cause. If successful, the students realize that they have moved to Zone 3, and in order to learn something new, they need to once again aim for Zone 2, choosing challenging tasks. Or, if the students are unsuccessful, they need to reflect on whether they might have been struggling in Zone 1 and therefore need some help. The teacher described that he aimed to change the students' beliefs about learning mathematics: "They need to understand that learning mathematics is a matter of 'hard work' in Zone 2 rather than a question of being smart." Thus, the teacher helped the students attribute outcomes of learning activities to causes they perceive they can do something about in contrast to causes that are out of their control. Attributing outcomes to a

cause facilitates the student's motivation to persevere and self-regulate in their own learning.

The teacher presented the Zones to the students by solving tasks on the whiteboard, starting with an easy task and talking aloud: "Okay, I know how to solve this one. I am in Zone 3. If I think I need to practice solving tasks like these I can do that, but I will not learn anything new by that." The teacher continued with a difficult task: "I have never seen this kind of task before. I do not recognize the concepts, and I am not sure what I am expected to figure out. Ah, I am in Zone 1, I need to ask the teacher to explain this." The teacher finally chose a task that he knew was challenging but within reach for most of his students. "Okay, I understand that this is an equation. But I have never solved one with two x terms. However, I know that my job is to figure out what x is. Okay, I am in Zone 2; it is difficult but I think I might solve this one, and when I do I have learned something." The teacher described that he wanted the students to observe him using the Zones, to learn how to assess which Zone they were in and to realize that in order to learn something new, they need to aim for Zone 2. Furthermore, the teacher used the idea of Zones when he presented 'asking a friend' as a beneficial task-solving strategy when the students encountered difficulties. To avoid the scenario where the students merely provided their fellow students with the correct answer, he presented and practiced feedback strategies for how to support a friend to solve tasks in Zone 2. That is, he suggested that the friend make a drawing, to solve an easier but similar task, to look at an example, and so forth.

To help the students engage in metacognitive reasoning, engaging in and moving between the zones, the teacher introduced the 'Inner Voice.'

4.3.2.2. The inner voice. The teacher presented the idea that their 'Inner Voice' could be that of a mathematician and discussed which properties would be appropriate for a mathematician's voice. Properties such as staying focused, not giving up, asking another mathematician, using strategies such as making a drawing were agreed upon. The teacher introduced the 'Inner voice' by using his own 'Inner voice' out loud while pretending to solve a difficult task at the whiteboard. The teacher had pre-recorded several examples of his 'Inner voice' that he played for the students while acting at the whiteboard. The students were invited to evaluate the teacher's 'Inner voice' starting with the following recording: 'This is difficult, I think I will look out the window instead,' or 'Hmm, I don't get it, I'll text my friend instead.' The students, rather amused by the teacher's efforts to mimic their way of avoiding difficulties, commented on his 'Inner voice' by pointing out that he should focus on the task at hand rather than distract himself. The teacher adjusted his 'Inner voice' accordingly by playing another example of his 'Inner voice': 'Okay, I better focus on the task, maybe I need to read it again, to make a drawing, to compare to other tasks I have already done, or perhaps ask a friend."

Furthermore, the teacher regularly invited the students to use his voice as their 'Inner voice.' This was done, for example, when the students solved tasks at the whiteboard and the teacher's voice provided the student with useful strategies to solve the tasks. Another example is when the students selected worksheets and the teacher's 'Inner voice' guided the students: "Okay, I know how to solve these tasks, these are Zone 3 tasks. But I would like to learn how to solve equations with x on both sides, then I need to choose Zone 2 tasks." By using the teacher's 'Inner voice,' the students developed their own 'Inner voice,' which they needed to choose appropriate tasks and strategies to solve those tasks. The teacher stated that the 'Inner voice' is the key to enhancing his students' self-regulation skills. "The inner voice is the most important part of their self-regulation, it is the 'thing' that keeps self-regulation going." For example, being in the 'Forethought Phase,' they need the voice to set the learning goals and to move on to the 'Performance Phase' by choosing suitable tasks to solve. They need their 'Inner voice' to use appropriate strategies to solve the chosen tasks, that is, staying in Zone 2 during the 'Performance phase.' Finally, they need the 'Inner Voice' to evaluate their efforts and learning outcome in the 'Self-Reflection Phase' and to eventually revisit the Forethought Phase to initiate their next cycle of Self-regulated learning by setting new or adjusting old learning goals.

To support the students' development of their 'Inner voices,' the teacher described the importance of gathering information about, and providing feedback targeting, the students' way of using their 'Inner voice' to their ability to act as self-regulated learners. However, since a student's 'Inner voice' is difficult to capture, he introduced the 'Invisible cloak' to monitor their self-regulating behavior driven by their 'Inner voice.'

4.3.2.3. The Invisible cloak. The teacher introduced the 'Invisible cloak' by explaining that when he wears the cloak (an imaginary one), he becomes invisible and they can just ignore him while he observes and provides feedback. The teacher connected his laptop to the classroom projector so everything he wrote was displayed for the students. The teacher observed his students' actions during the lesson and gave written feedback accordingly, such as: "Lily has some difficulty, but she examines some of the earlier tasks she has solved to get some ideas; that is a good strategy." "Mia chose a worksheet with tasks she never worked with before, now she is in Zone 2, that is a good strategy." "Ben has been looking out of the window for a fairly long time, that is probably not a good strategy… But now Ben starts to work. Good choice!" The teacher described how the students thought that this was fun and became very engaged in trying out a variety of actions to see what feedback they would get. That gave him the opportunity to provide feedback on, for example, promoting good strategies to choose learning goals to enter Zone 2 and to choose task-solving strategies to remain in Zone 2. This way of providing feedback was commented by the students as well: "It was great when he wrote about my and my friends' way of dealing with difficult tasks." "It is a bit ridiculous when he turns invisible. But it is actually good to not always have the teacher to ask, then you need to think about other ways to solve a difficult task."

4.3.2.4. Constructing test-tasks. The teacher expressed difficulty discussing learning goals at the beginning of a content area, such as equations, since the students did not have an oversight of what was to be learned. However, after working with equations for a couple of lessons, they started to get a feel for what equations are all about and what they are expected to learn. Then, the teacher introduced the activity 'Constructing test-tasks' to discuss learning goals. The teacher presented the activity, inviting the students to observe, by writing unsolved equations and tasks (Constructing test-tasks) on the whiteboard. The teacher then initiated a discussion about what kind of knowledge a student may show by solving each task. The teacher said that "this is a good way of discussing and agreeing on learning goals, since the students now know 'what we are talking about'." The students were then asked to construct their own test-tasks aiming for their individual learning goal. They could construct tasks in relation to any of the three zones, knowing what they needed to prepare before the real test in which their tasks would be included (along with some of the teacher's tasks). The students commented on this activity with statements like: "I like the idea that I can choose test-tasks that I see that I have just learned (or know that I will learn) how to solve." "I like to aim high, and know what to strive for."

4.3.2.5. Worksheets. The teacher provided a mix of Worksheets (with respect of content and difficulty) for the students to choose from. The teacher introduced the Worksheets, talking out loud and using his 'Inner voice,' which told him to choose tasks according to what he was trying to learn (Zone 2) or what he needed to practice (Zone 3). In the beginning of the intervention, the teacher also reminded them to "Look at the tasks to make sure you choose the right Zone… if you want to learn, you need to be in Zone 2, if you feel that you need to practice, you can stay in Zone 3."

4.3.2.6. Practice tests. The teacher constructed 'Practice tests' similar to ordinary mathematics tests. The purpose was partly to have further discussions about learning goals and to provide information about students' misunderstandings that needed to be addressed, but mainly to support the students' ability to evaluate their own achievements. When taking 'Practice tests', the students were allowed to use all kinds of support and their results did not have any negative impact on their grades. When the teacher had scored and returned the 'Practice tests', the students were given the opportunity to work with the tasks once more to improve their scores. When returning the tests, the teacher could provide feedback such as: "I saw that you did not get the opportunity to show that you know how to solve equations with x on both sides. Now you have a chance to work on these kinds of equations and then, if you like, show me that you know how to do it." The teacher had prepared worksheets that the students could choose from to practice skills that the 'Practice test' had shown they need to develop. As the teacher informed the students: "If the 'Practice Test' showed that something seems to be difficult, and you think you are in Zone 2, then there are sheets on my desk to choose from. If you are in Zone 1, just tell me and I will help you." The teacher told the students that returning the 'Practice tests' provides a good opportunity to point out the students' success that resulted from the strategies they used in choosing tasks and task-solving strategies that are beneficial for their learning. The observer noted that this way of giving feedback to students, pointing out success as a result of their own hard work and good learning strategies, also occurred frequently in other learning situations beyond the 'Practice tests'. The students described the 'Practice tests' as highly beneficial: "'Practice tests' are good, you find out what you don't understand and can ask for help," "They show me what I need to practice on." "You can't fail a 'Practice test', so you can be calm and think."

4.3.3. Formative assessment practice as support for the development of self-regulated learning

The implemented classroom practice was aligned with all seven principles proposed by Nicol and Macfarlane-Dick (2006) in terms of how formative assessment processes can support the development of students' self-regulated learning. The classroom practice included activities aimed at facilitating a shared understanding of the learning goals (Principle 1, P1), for example, when discussing and constructing test tasks. The teacher also frequently used several methods to gather information about students' knowledge and skills in relation to the separate, but not unrelated, learning goals of mathematics and self-regulation (P2). The teacher often used all-response systems to gather information about *all* students' mathematical learning, for example, through small tests and the use of small whiteboards during whole-class settings and feedback based on the information acquired about their learning needs (P3). In addition, the teacher created opportunities for the students to practice self-regulatory skills (P4) and frequently gathered information about the students' use of these skills (P3), for example, when using the 'Invisible cloak.' The teacher then used this information to provide feedback that targeted learning needs in all phases of the self-regulation process (P3). The teacher's feedback often included information about what the students had done well and indications of how they could improve their learning. In this way, students continuously received information against which they could both compare their own internal constructions of goal criteria and monitor and self-assess their progress. The students were also provided with opportunities to discuss feedback with the teacher and peers in relation to criteria and standards so that they could deepen their understanding of its meaning and usefulness in relation to their own internal self-regulatory feedback processes (P5). Furthermore, the teacher supported motivational beliefs, such as perceived autonomy and self-efficacy, that drive the self-regulation processes (P6). Perceived autonomy may have been facilitated when the teacher supported his students to act as proactive agents in the formative assessment processes of identifying learning needs and adapting behavior accordingly. For example, the students were supported in their use of their 'Inner voice' to choose learning goals and corresponding learning tasks in the 'Forethought phase,' to provide themselves with feedback (task-solving strategies) that would help them remain in the 'Performance phase' and to engage in self-assessment in the 'self-reflection phase' so they could evaluate their learning and decide how to proceed. Self-efficacy may have been facilitated when the students could experience learning success through structured opportunities to close the gap between their current and desired performance (P7). Such opportunities include the possibility to work with tasks on the Practice Tests again after they had been scored. The many opportunities to experience success due to proximal goals that were frequently set and evaluated and the teacher's feedback (P6) when helping students attribute outcomes to effort and strategies - which are causes susceptible to change and can be controlled by the students - may also enhance self-efficacy.

In addition, the formative assessment practice provided support for the students' development of SRL skills in all three phases of SRL and at all four developmental levels of the regulatory skills. For example, the teacher supported the students' development of an 'Inner voice' to guide their self-regulation. The teacher modelled the use of the 'Inner voice' by 'thinking aloud' and letting the students hear his reasoning about which worksheets to choose (goal setting and planning in the forethought phase), how to focus attention on learning and task-solving when working with the tasks (method of self-control in the performance phase) and how to evaluate whether task-solving has improved enough to redesignate certain task types from Zone 2 tasks to Zone 3 tasks and move on to more difficult tasks (self-assessment in the self-reflection phase). The teacher also described the characteristics of his reasoning and the reasons for these characteristics, and he engaged in discussions with the students about these characteristics (Level 1). The students also had the opportunity to provide feedback to audio-recordings of the teacher's 'Inner voice' and to practice their 'Inner voice,' for example, by thinking aloud when solving tasks in front of the class, sometimes followed by a discussion of the characteristics of the 'Inner voice' that was used (Level 2). Furthermore, the teacher structured opportunities for the students to practice their 'Inner voice' on their own by telling them to use it during seatwork sessions. The teacher then used the 'Invisible cloak' when giving feedback on their 'Inner voices' and helped them to use their self-assessments of the 'Inner voices' to improve their learning (Level 3). The feedback targeted, for example, the same strategies he had modelled himself. After some time, the students were expected to use their 'Inner voice' without being prompted, and the teacher sometimes left the room and came back to look for indications of how the 'Inner voices' were being used (e.g., if the students were at all still working with learning tasks, the type of questions they might have for the teacher or peers, etc.) (Level 4).

5. Discussion

The results of the study show that the formative assessment practice described had a significant effect on both motivational beliefs and behaviors involved in the self-regulation of learning. Perceived autonomy does not seem to be a commonly used construct in studies of the effects of formative assessment interventions on students' SRL, but the effect of formative assessment practice on perceived autonomy was very large in this study. In addition, the effect on self-efficacy is much larger than what was observed in other interventions aimed at enhancing students' SRL (Meusen-Beekman et al., 2016; Panadero et al., 2012; Smit et al., 2017). The significant effects on these two motivational beliefs mean that the students' perception that they had the opportunity to influence how to learn as well as the belief that they are able to learn increased significantly. The change in SRL behavior was also striking. At the beginning of the intervention, the vast majority of the students only engaged in learning activities initiated by the teacher and were not engaged in the Forethought, Performance or Self-reflection phases at any of the four levels of regulatory skills. After the intervention the

students set learning goals and, without being prompted by the teacher, initiated learning activities, used several strategies to stay focused and monitor their learning, evaluated their learning outcome, and decided what needed to be learned and practiced to reach their learning goals based on this evaluation. Thus, they were engaged in true self-regulated learning practice on the self-control and self-regulation level, encompassing all three phases in the cyclical process of self-regulation.

In general, measurements of SRL have most often been made using self-report instruments (Roth, Ogrin, & Schmitz, 2016), and in particular conclusions about the effects of formative assessment on the students' motivational beliefs, skills and behavior involved in self-regulated learning have mainly been based on students' self-reports. Although self-reports certainly have value, they do have some general limitations (Veenman, 2011), such as the possibility that students may respond in a way that "makes them look good" and the difficulty of giving accurate accounts of, in particular, behavior. In addition, questionnaire items about students' SRL behavior have commonly asked students to what extent they use specific SRL skills. But students' self-reports rarely distinguish between whether these skills are used together in a cyclic process or if they are used continuously on their own initiative in regular classroom practice. And these are prerequisites for a truly self-regulated learning practice. Thus, research reviews have called for complementing self-reports with other measurements of SRL (Panadero et al., 2018), and studies investigating the effects of classroom practice on true SRL (McLaughlin & Yan, 2017). In the present study, self-reports of the students' SRL behavior were complemented with classroom observations, providing more direct evidence of the students' SRL practice in their classrooms. In addition, both the researcher's and the teacher's classroom observations and students' responses in the interviews indicate similar developments in the students' SRL practice, which enhance the confidence in the findings.

The study shows the advantage of a classroom practice that is not only focused on one single aspect of formative assessment, such as self-assessment, but a practice that integrates several aspects of formative assessment. The fact that both the teacher and students acted as proactive agents in the formative assessment processes when gathering and acting on information regarding the students' learning of both subject matter knowledge and SRL skills made it possible for the practice to be aligned with theories of how students' SRL may be supported in general (Zimmerman, 2000) and by formative assessment in particular (Nicol & Macfarlane-Dick, 2006). In line with these theories, the effects from the formative assessment practice on the students' SRL was substantial. The effects on SRL are also consistent with the theoretical arguments made by Panadero and Broadbent (2018) that formative assessment may influence SRL in all phases of Zimmerman's SRL model, and with other theoretical frameworks for how formative assessment may influence students' SRL development (Andrade & Brookhart, 2020; Chen & Bonner, 2020). Thus, the present study provides empirical evidence of what highly effective formative assessment with large effects on students' SRL may look like and how it fits with theory. Such empirical evidence is important to substantiate existing theories of how formative assessment may influence students' SRL development, and there is a lack of studies on the effects on SRL that includes comprehensive descriptions of formative assessment practices in which both the teacher and the students are proactive agents in the formative assessment processes. The analysis of the classroom practice shows that, in line with the contention by Allal (2011) and Andrade and Brookhart (2020), students' use of SRL skills often were co-regulated by the teacher, peers and curriculum material such as the availability of practice sheets to choose. However, students in this study began to also exert truly self-regulated behavior, for example evidenced by their actions when the teacher was not in the classroom.

Based on the results of the study, there are at least three kinds of future studies that would be valuable contributions to this research field. Firstly, the practice described in the present study is complex and not easy to carry out. Therefore, studies on what is required from professional development programs so they may successfully support teachers' development of practices similar to those in the present study would be valuable. Secondly, case studies that focus solely on a qualitative methods approach may be able to provide an in-depth examination of the underlying mechanisms by which different characteristics of the formative assessment practice affect students' SRL development. Thirdly, a limitation of this study is that we have only investigated the formative assessment practice of one teacher. Although theory is well aligned with the data and conclusions in the study, it cannot be ruled out that the effects found were due to something else than the characteristics of the implemented formative assessment practice. The small number of students in the intervention class might also have had an impact on the results. It is reasonable to assume that larger classes will add complexity to the formative classroom practice. Therefore, it would be useful to complement this study with studies involving larger and different kinds of teacher and student samples to be able to make valid generalizations across different samples of teachers and students in different contexts. We imagine that the main idea, to support students' ability to develop strategies to take and maintain control over their studies, is possible to implement in different learning environments. However, the didactic design with respect to, for example, gathering information about students' learning needs and to provide individual feedback must be adjusted to suit the group size and the age of the students. For example, for large student groups, the 'practice tests' can be corrected and commented on by peers and mini whiteboards used as student response tools may be replaced by digital response tools. For older students, the 'invisible cloak' can be replaced with individual and peer reflection.

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