A review of the impact of formative assessment on student achievement in mathematics

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Research reviews show that formative assessment has great potential for raising student achievement in general, but there is a need for reviews of formative assessment in individual subjects. This review examines its impact on student achievement in mathematics through an assessment of scientific journal articles published between 2005 and 2014 and indexed in *Web of science*. Through the use of search terms such as ″formative assessment″, ″assessment for learning″ and ″self-regulated learning″, different approaches to formative assessment were included in the review. While varying in approach, they all share the defining characteristic of formative assessment: agents in the classroom collect evidence of student learning and, based on this information, adjust their teaching and/or learning. The results show positive relations between student achievement in mathematics and the ways of doing formative assessment included in the review.

Previous research surveys (Black & Wiliam, 1998a) and meta-analyses (Hattie, 2009) have concluded that formative assessment is one of the most effective ways to raise student achievement. Both Black and Wiliam and Hattie concluded that this applied to students of different ages and in different school subjects, and they indicated effect sizes in the range 0.4–0.7 (Black & Wiliam, 1998b) and 0.5–0.9 (Hattie, 2009, p. 297). Very few articles have questioned the conclusion that formative assessment has great potential, but a number have questioned the large effect sizes and the quality of certain studies. They suggest that the research available is insufficiently robust for drawing far-reaching conclusions concerning all ages and subjects (e.g. Bennett, 2011; Dunn & Mulvenon, 2009; Kingston & Nash, 2011).

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There is, therefore, a need for further research reviews of formative assessment and its impact on learning in genera[1]. In addition, there is a need for reviews of formative assessment in individual subjects such as mathematics because the different character of subjects may affect how formative assessment should be done. Views on this vary between representatives of different subjects such as, for example, mathematics and languages (Bennett, 2011; Hodgen & Marshall, 2005). Empirical studies have also shown that the effects of similar interventions in different subjects have outcomes of different sizes (e.g. Dignath & Büttner, 2008; Yeh, 2009). Yet, most commonly, reviews on the effects of formative assessment do not distinguish between studies in different subjects. An exception is a review by the U.S. Department of Education (National Mathematics Advisory Panel, 2008), but they only examined a few studies, focusing mostly on special education. Based on the research need identified above, the review presented in this article1 focuses on the following research question: To what extent does formative assessment have an impact on student achievement in specifically mathematics?

The concept of formative assessment

Formative assessment is a way of teaching and learning, and must not be confused with assessment processes carried out for grading and selection (normally called summative assessment). One difficulty with the conclusions and compilations of research results on formative assessment is that the term has been used with slightly different meanings, although with the same basic sense. These variations might create different results in research studies. In this research review, formative assessment is conceptualised as follows:

> Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about next steps in instruction that are likely to be better, or be better founded, than the decisions they would have taken in the absence of evidence that was elicited. (Black & Wiliam, 2009, p. 9).

This definition allows for formative assessment to be carried out in different ways and with different focuses. All of these approaches share the defining characteristic of formative assessment that agents in the classroom collect evidence of student learning and, based on that information, adjust instruction to improve student learning (*instruction* here includes both teachers' and students' activities). However, research within the area of formative assessment is conducted under different names and with a focus on different aspects.

In one approach to formative assessment, the focus is on the teachers' frequent gathering of information about their students' learning, and the resulting modification of their teaching to meet the students' identified learning needs. This may include teaching adjustments both in the teacher using the information to make decisions on overall strategies in the classroom and in using it to lead the students further in their learning through, for example, explanations and supportive questions. In both cases, the teacher may include feedback to support a change in less functional conceptual views and solution methods. The terms used for this approach to formative assessment are usually *formative assessment*, *assessment for learning* or *formative evaluation*.

In a second approach to formative assessment, the focus is on the feedback that teachers give to students based on the evidence gathered on the students' learning. In these studies, the focus is on the *characteristics* of the feedback, which is not emphasised in the first approach. *Feedback* from the teacher is expected to initiate cognitive and/or emotional processes amongst the students, which, in turn, affect their motivation and performance (Rakoczy, Klieme, Burgermeister & Harks, 2008). There are different definitions of the concept of feedback in the literature. A common definition describes feedback as information from a person or a material concerning someone's performance or understanding (Hattie & Timperley, 2007). Feedback is thus always a response to a preceding action. The meaning of feedback in all the studies included in this research review lies within this definition. The effect that feedback has on student achievement depends not only on whether a student receives feedback, but also on the characteristics of the feedback (Kluger & DeNisi, 1996). It is possible to differentiate between different types of feedback and different forms in which feedback is given and received. Two examples of different types are feedback that speaks of whether something is correct and feedback that provides additional information. The form in which feedback is given may be, for example, verbal or written form, by an adult, a peer, or from a book, oneself or a computer program. Feedback may be given during or directly after a task is attempted or later on as delayed feedback. Feedback can also be received in different ways, for example, individually or in a group.

In a third approach, the focus is on the students modifying their learning based on their own assessment. In addition to responding to teachers' adapted instruction and feedback, the students' may take the role of self-regulated learners, which includes planning, monitoring, reflecting on and modifying one's learning (Zimmerman, 2002). Thus, *self-regulated learning* involves *self-assessment* and subsequent actions, based on the information from the assessment, to attain the learning goals. The students elicit evidence of their own achievement in the monitoring and reflecting phases, and then use this evidence to modify their learning. The self-regulation processes may be conducted in different situations, such as when learning through solving a task or listening to a teacher's lecture. The self-regulation may be directed at different achievements, including answers to tasks, strategies for finding answers or solving tasks and the use of resources in the learning process, such as the time and effort used for learning.

In a fourth approach to formative assessment, the focus is on how the students' role in the formative assessment practice may be to support each other's learning through *peer-assisted learning*, which involves *peer assessment* and subsequent feedback through explanations and suggestions to peers on how they can act to reach their learning goals. Finally, a fifth approach is to include all of the four approaches in classroom practice (e.g. Wiliam & Thompson, 2008). The terms used for this last approach to are usually *formative assessment* or *assessment for learning*.

Existing reviews on the impact of formative assessment

The research review from the U.S. Department of Education (National Mathematics Advisory Panel, 2008) includes an investigation of the effects of teachers using information from frequently administered small tests to provide differentiated instruction for students. The researchers concluded that formative assessment in mathematics has great potential for raising student achievement, but that not enough high quality research had been done to draw more reliable conclusions on this effect. Owing to the search criteria, the review covers only 10 individual studies and they focused mostly on the elementary school level and on special education students. General research reviews that focused on the second approach to formative assessment but not on mathematics concluded that feedback can have a major impact on achievement (Hattie & Timperley, 2007; Shute, 2008). There is no "best" type of feedback for all learners in all situations, and major gaps remain in the research literature (Shute, 2008). At the same time, some general guidelines for effective feedback can be found in these reviews. For example, to be most effective for learning, feedback should usually make it clear both about how the students are doing in relation to the learning goals and how they may close any gaps. Studies also consistently show that students who self-regulate their learning, including modifying their learning based on self-assessments, generally are successful in their academic achievements (e.g. Zimmerman

& Bandura, 1994; Zimmerman, 2001). Reviews across subjects have also shown that students' self-assessment and teacher support for students' self-assessment may enhance student learning (Panadero & Jönsson 2013; Ross, 2006). Likewise, research reviews across several subjects have shown that peer-assisted learning, including peer assessment and peer-feedback, is positive for student learning (Rohrbeck, Ginsburg-Block, Fantuzzo & Miller, 2003). Finally, a few individual studies, but no reviews, have shown that formative assessment practice that includes all five approaches can have a positive effect on student achievement in mathematics (Andersson & Palm, 2017; Wiliam, Lee, Harrison & Black, 2004).

Method

The study process for this literature review was carried out in accordance with the conceptual framework for systematic review by Gough, Oliver and Thomas (2013). This framework has ten stages: need, review question, scope, search, screen, code, map, appraise, synthesise and communicate. The first two stages concern the choice of people to carry out the review and a decision on which research questions to use. The stages pertaining to the scope of the review (criteria for the selection of studies), search strategy, screening, coding, and appraising the quality of studies, structure the methods section. In this study, the mapping of the research field comprises the list of articles found in the literature search. These articles are listed in appendix 1, which is divided into three sub-groups according to three different approaches to formative assessment described in the introduction. The results section presents findings from the individual studies pertaining to each sub-group, followed by a synthesis of these findings.

Scope (inclusion criteria)

In the search of articles with relevance for the research question, the scope included using only the *Web of science* database. An advantage of Web of science is that the database includes publications within different scientific disciplines that carry out research on formative assessment in mathematics. It also covers several high quality mathematics education journals for large sections of the publication period chosen. A disadvantage with Web of science is that the database does not include all mathematics education and assessment journals.

The search covered the years 2005–2014 in order to not miss articles published after the reviews discussed above. The search was limited to scientific journal articles. This limitation does not necessarily significantly affect the inclusion of important studies. Most important research results in high quality research should have been published in a scientific journal.

Search strategy

The search for articles for this review involved the use of several different terms for teaching and learning processes that can be characterised as being formative assessment according to the definition by Black and Wiliam (2009). This definition captures the same core idea used in the review by Black and Wiliam (1998a) that appears to be the most cited article within the field. In the present study, the terms used to search for articles are called *search terms* and the terms used to search for the same purpose are designated as a *search group*. The search group called *formative assessment* includes, for example, the search terms ”formative assessment”, ”assessment for learning”, ”feedback” and ”self-regulated learning”. Thus, formative assessment will sometimes be used in the sense of a search group and sometimes in the sense of a search term. The sense in which the term was used can be understood from the context in which it was used. In order for the search to produce an outcome in literature relevant for the research question and context of this study, search terms were also used for the search groups *mathematics* and *students*. The search terms and the search groups are presented in table 1. In the search, different spellings were used so as to include variants of a search term. For example, the search term ”self-assessment” was used with the variants ”self-ass*”, ”selfass*” and ”self ass*”[2]. In the search process, the terms in the formative assessment group were looked for in the title of the article. In most articles where the focus is on formative assessment, these terms are likely to be in the title. In order for a publication to be included in this research review, a search term for the mathematics group and for the students group had to be found in the material on the topic (title, abstract or keywords). Such terms are often not found in the title. Requiring such search terms to be found limited the number of articles identified to those most relevant for the research questions. The search did not, for instance, retrieve studies on feedback in environments other than a school.

Screening

Through the search, 104 articles were identified. The abstracts of these articles, and, where appropriate the whole article, were then read to make decisions on their relevance for the review's research question, and for

Table 1. *Search groups and search terms*

Search group	Search terms	Location of search
Formative assessment	formative assessment, assessment for learning, formative evaluation, self-assessment, self-regulated learning, peer assessment, peer-assisted learning, feedback, response-system	title
Mathematics	mathematics	topic
Students	student, pupil	topic

final inclusion in the review. Articles that contained empirical studies, quantitative or qualitative, that dealt with the review's research question for the school subject mathematics in years 1–9 or in upper secondary school were kept. Then a determination was made about whether the practices described in the studies could be considered formative assessment. This was done by comparing the characteristics of these practices with the definition of formative assessment by Black and Wiliam (2009). Studies not included in the review were those that, for example, did not empirically investigate the relation between formative assessment and student achievement; studies using the term "feedback" meaning providing new information instead of information about aspects of students' preceding actions; and those pertaining to self-regulation processes that did not include actions to attain learning goals based on self-assessment. A total of 23 articles remained for in-depth analysis to answer the research question (see appendix 1).

Coding

The practices in the articles were coded according to which of the five approaches to formative assessment, they belonged. For example, a practice in which students carry out self-questioning, including questions aimed at their understanding during the task-solving process and if whether answer is correct and what to do if it is not, would be coded as belonging to the third approach. To answer the research question concerning the impact of formative assessment on student achievement, we identified the levels of significance from the hypothesis tests, effect sizes (standardised differences in mean values between group results) and other measurements of the strength in associations indicated in the studies. These measurements comprised the basis for drawing conclusions on the impact of formative assessment on student achievement. No meta-analysis of the constituent studies was made. When research cover subjects so diverse as the different approaches to formative assessment, any form of mean value of measures of association would have no clear meaning (Black & Wiliam, 1998a, Bennett, 2011). Instead, the size of the association measures provided in individual studies, or the range of sizes in several similar studies, has been specified.

Appraising the quality of studies

In the work for this review, no assessment was made of the quality of the constituent studies because all the articles in the Web of science are in peer-reviewed publications, which should imply that the studies have a fundamental quality. Based on the discussion carried out in the research community concerning the quality of published studies (e.g. Dunn & Mulvenon, 2009; Kingston & Nash, 2011), it cannot, however, be ruled out that some studies may have quality shortcomings.

Results

This results section presents findings for three types of formative assessment found in the articles reviewed: teachers gathering information, feedback, and student self-assessment (first three approaches). No articles focusing on peer assessment (fourth approach) or the use of integrated approaches (fifth approach) were found in the literature search. (see appendix 2 for the characteristics of all the articles included in this review).

Teacher assessment with subsequent instructional actions

Four of the studies, including one review which contained two studies (Yeh, 2009), investigated the effects of teachers gathering information about student achievement and providing instructional actions or feedback based on the information. The measure of mathematics achievement included different aspects of mathematics assessed by standardised tests or selected items from standardised tests, a test intended to measure general mathematical ability, and tests for conceptual understanding and application of procedures. In all the studies except one, the positive effect of this approach to formative assessment was statistically significant for the whole student group on at least one measure of students' mathematics achievement. Effect sizes were not always provided, but in the four studies providing such a measure, the effect sizes for the significant effects lay between 0.2 and 0.8, which according to Cohen (1988), can be regarded as a small and large effect, respectively. Yeh (2009) concluded formative assessment was 124 times as cost-effective as class size reduction.

Most of the studies reported that computer programs were used as a tool in the formative assessment practice. In the studies investigated in Yeh (2009), computer-based adaptive tests were used 2–5 times a week with individual feedback then being given to the relevant students. The teachers received information in summary form concerning the performance of the class as a whole and of individual students. The information was used to adapt the teaching to the identified learning needs of the class and of individual students. The teachers had participated in short training sessions about how the information from tests could be used to make decisions concerning future stages of the teaching. In the two studies by Burns et al. (2010) and Koedinger et al. (2010), computer programs were also used as a support for the teachers' teaching. In the first of these studies, the TEFE program was used; it generates worksheets for the students, corrects them and notifies the teachers when it is time to test individual students. The program also corrects the test and generates new worksheets as and when needed. The teachers obtain information for each student and then have a basis for making decisions on their teaching. In the study by Koedinger et al. (2010), the ASSIST program was used; it generated small tests frequently and correct tests. It also offers students corrective feedback and helps them with hints and supportive questions.

The study by Phelan et al. (2011) differed from others in this group in a few ways. It used a non-computerised supporting material (Powersource), which was intended to help the teachers to regularly collect information on the students' learning and to support the teachers' follow-up teaching based on this information. It also differed in that the intervention was undertaken during a much shorter period, over just eight lessons while the implementation period of the other studies ranged from half a year up to more than five years. In addition, the participating teachers received very little training in Powersource despite not having a computer program doing much of the assessment and feedback work. This study was the only one that did not provide significant effects on the entire group studied.

Feedback

Eight studies on feedback are included in this review. The students' mathematics achievement were measured by tests on mathematical facts, procedures and conceptual understanding. Five studies compared the effect of feedback with no feedback or less frequent feedback on student achievement in mathematics. Four of these studies made a comparison with control groups (Brosvic, Dihoff, Epstein & Cook, 2006; Clarke et al., 2014;

Dresel & Haugwitz, 2008; Labuhn, Zimmerman & Hasselhorn, 2010). The fifth study compared the effect of feedback as a function of how frequently the students obtained feedback of different types (Rakoczy et al., 2008). In the study by Brosvic et al. (2006), the students' increase in mathematical achievement was statistically significantly greater for the group who received immediate feedback at the task level (feedback which indicates if an answer is right or wrong) than for the group that did not receive any feedback. Similarly, Dresel & Haugwitz (2008) found that students provided with attributional feedback improved their achievement significantly more than a control group not given any feedback. In the study by Clarke et al. (2014), the students were taught in small groups where one of several components was to offer feedback to the students to confirm their correct answers and to correct possible misunderstandings. In the Clarke et al. (2014) study, the effect on student achievement was significant for proximal measures of student achievement but not for distal measures (the distal measure being the Stanford achievement test). Brosvic et al. (2006) did not provide any effect sizes while the effect sizes in Dresel and Haugwitz (2008) and Clarke et al. (2014) were 0.5 and 0.8 respectively. Significant effects of feedback were not found in the studies by Labuhn et al. (2010) and Rakoczy et al. (2008). Here, however, it can be established that the type of feedback given in the Labuhn study was of a nature that other studies have shown to be less effective for learning (see e.g. the description by Brosvic et al., 2006 below). Here the feedback was not given on each task or assignment but only as a combined result for a set of tasks or assignments, and the time for learning from the feedback was very short. The students received feedback on a single occasion and then had 10 minutes to process it. It would likely be difficult to cognitively process this information in a way that is feasible for learning. In addition, the effects that feedback can have on students' motivation may be limited in such a short intervention. The study by Rakoczy et al. (2008) (which examined the effects of feedback given with different frequency) took no account of the quality in the feedback. Each student may have obtained relatively little feedback since the study was undertaken during only three lessons in the ordinary classroom environment and the teacher did not receive any instructions on providing feedback. These factors would likely have influenced the effect on student learning.

Four of the studies compared the effect of different types of feedback or the effect of when and how feedback is given. The study by Cates (2005) of four students showed that where feedback is given at the task level, it may, for certain students, be more advantageous to obtain the feedback from a computer than from a classmate, whereas for other students it may be the opposite. In the study by Brosvic et al. (2006) of a larger sample of students, no statistically significant difference was seen between the groups of students who received computer-generated feedback at the task level and those who received the same type of feedback from the teacher. On the other hand, the students learned more when they obtained feedback (on a task level) after each task compared to when they obtained it after they had answered all the tasks in one session (Brosvic et al., 2006). Rakoczy et al. (2013) compared the effects of written process-oriented feedback (tips on how to improve or a strategy how to solve a problem) and feedback in the form of grades on a set of tasks on student achievement. No direct statistically significant difference was found between the groups. However, a statistically significant indirect effect on student achievement, via the perceived usefulness of the feedback, was found in process-oriented feedback compared to feedback in the form of grades. In the study by Roschelle et al. (2010), students who received task feedback at the small group level (and were to process it together) learned more than those who obtained task feedback at the individual level.

Self-assessment with subsequent actions

Of the 12 articles on self-regulated learning activities, including students' self-assessment and subsequent actions, one is a review (Montauge, 2008), one a meta-analysis (Dignath & Büttner, 2008), and five others analysed intervention studies. Four articles included correlational studies which measured students' self-regulation and achievement in mathematics, and one article investigated the correlation between teachers' support for self-regulation and student achievement (Kistner et al., 2010). In some of the studies, mathematics achievement was measured by grades, in others by an overall teacher judgement. The exact aspects of mathematics captured by these general measurements are not clear. In still other of the studies, tests focused on problem solving or basic arithmetic skills. Some studies did not define mathematics achievement.

All of the intervention studies reported a significant positive effect on student achievement. Based on an "overall analysis of the studies as a group", the review by Montague (2008) concluded that strategy instruction, including teaching aspects of self-regulation to students, is an evidence-based instructional approach for improving achievement for students with mathematical disabilities. In the meta-analysis by Dignath and Büttner (2008), which analysed intervention studies with a focus on self-regulated learning, the mean value for the effect sizes was 0.96 for school years 1–6 and 0.23 for the school years 7–10. In the studies using effect sizes when comparing self-regulated learning practices with other types of practices, the effect size varied between 0.4 and 0.8 (Dresel & Haugwitz, 2008; Kramarski & Gutman, 2006; Kramarski & Mizrachi, 2010). In the study by Lazakidou & Retalis (2010), the students' improvement from a pretest to a different but structurally similar posttest was 2.4 %. In the case study by Ness and Middleton (2012), the student attained a higher grade.

The formative assessment component in these studies all involved self-assessment and actions based on this assessment, but differed in what aspects of achievement the students self-assessed. In the review by Montague (2008), the interventions reviewed involved different components, but the formative assessment component embedded in the teaching strategies comprised self-questioning techniques. These included questions directed at the students' understanding of the task-solving process, whether the answer was correct and what to do if it was not. The meta-analysis by Dignath and Büttner (2008) included studies involving different aspects of self-regulated learning, one such aspect being self-assessment. In Kramarski and Gutman (2006) and Kramarski and Mizrachi (2010), self-metacognitive questions were taught to the students, for example, questions directed at having them evaluate their achievement in terms of their answers to learning tasks and reflect on the suitability of their task-solving strategies. In Dresel and Haugwitz (2008), the students were given questions from a mathematics learning software program to prompt their self-assessment of their present knowledge, whether their learning and task solving were going according to plan and possible actions to improve their performance based on their self-assessment. The instructional method used in Lazakidou and Retalis (2010) included a broader task-solving method and having students assess the problem-solving process, and how they could reuse aspects of this process on future problems. In Ness and Middleton (2012), a special education student was supported in daily self-assessment of achievement in learning and management of learning resources, such as material and time, and how to improve in these areas.

All but one of the correlation studies showed correlation between formative assessment components and student achievement. Metallidou and Vlachou (2010) found a statistically significant correlation (corr = 0.8) between student achievement and students self-evaluating their test results, seeking further information from the teacher about the achievement and seeking assistance in learning activities. Rosario et al. (2013) found a correlation (r = 0.4) between achievement and students using self-regulated learning strategies in all three self-regulated learning phases: planning, executing and self-assessment. The self-assessment component included the students comparing the grades they received with the goals they had set. Marchis (2012) found correlations (corr = 0.3) with students' self-regulation skills, including checking the results, whether all data given in the task had been used and what was not understood when difficulties appeared. Ocak and Yamac (2013) found no correlation between students' self-reported self-regulation strategies and their grades. Kistner et al. (2010) investigated the correlation between teachers' observed instruction and the students' improvement in understanding of proof. They found that explicit instruction in self-evaluative directions such as "While working on this kind of task, you should always ask yourself: What do I already know? and What am I looking for?" significantly improved students' understanding (r = 0.5). They also found that self-evaluative directions like "Check your results again" did not. Implicit instruction did not correlate with increased achievement.

Synthesis

The analysis of the articles that were included in this review shows that all three approaches to formative assessment can have a positive impact on student achievement in mathematics. These approaches share the underlying feature of modifying teaching or learning in accordance with identified learning needs. Teachers can implement this core practice of formative assessment by frequently using tests to gather information on student learning and using it to adapt their instruction or feedback to better meet their students' identified learning needs. The students themselves may implement the core practice by taking an active part in the formative assessment process. This may be done by teachers helping their students to become self-regulated learners who assess their own understanding and skills and use the information to adapt their learning to achieve their learning goals.

The effect sizes varied between being low (0.2) and large (0.8), and the effects have been shown for different aspects of mathematics, including application of procedures and problem solving. A statistically significant effect on student achievement was found for all studies in which the common component was that tests were used to frequently collect information on the students' learning and that the teacher adapted their teaching in accordance with the students' identified learning needs. In these studies, computer software were often used to generate tasks and information about students' achievement. In addition, feedback may have a positive effect on student learning, but the type of feedback is crucial for this effect to occur. Feedback at the task level, as well as attributional and elaborated feedback, were shown to affect achievement.

However, the feedback needs to be given so it is possible for the students to process and act on it, preferably in small groups, and should not be provided as a combined result from a number of tasks. Furthermore, the studies showed a strong relation between student achievement in mathematics and with both self-assessment with subsequent actions based on this assessment and interventions supporting this component of formative assessment. Associations with high achievement were found for self-assessments and subsequent actions targeted at students' task-solving processes and at their management of learning resources. Such associations were found for this formative assessment component alone and when it was combined with other task-solving processes or self-regulated learning processes.

Discussion

This review adds to the existing literature on formative assessment by showing that the positive impact of different approaches to formative assessment on student achievement, which have been found in general, hold specifically for mathematics. This is important because the concrete implementation of formative assessment practices may differ between subjects due to their different character (Hodgen & Marshall, 2005), and outcomes of different effect sizes have been found for similar formative assessment interventions in different subjects (Dignath & Büttner, 2008; Yeh, 2009). The positive effects on mathematics achievement found for modification of teaching based on information gathered from small and frequently used tests (the first approach to formative assessment) are in line with the conclusions made in the review by the National Mathematics Advisory Panel (2008). This review goes further than that review in that it includes studies representing a broader array of student groups. In addition, this review provides insights on the use of computer programs in formative assessment, an area of research that the National Mathematics Advisory Panel (2008) identified as lacking. This review shows that the use of such software has a positive impact on student achievement. It also shows that feedback (the second approach) can enhance achievement in mathematics and that the type of feedback is crucial for achieving the effect, a conclusion also drawn in reviews of the effect of feedback on school achievement in general (Hattie & Timperley, 2007). Furthermore, the current study indicates the importance of providing students with good opportunities to process and use the feedback for improving their learning. The positive effects of self-assessment and subsequent actions as an approach to formative assessment (third approach) is in line with the promising results found in the general reviews investigating the effects across different subjects (Panadero & Jönsson, 2013; Ross, 2006). The current review provides additional insights by describing how this approach can vary in mathematics and still have an effect on achievement. Lastly, this review seems to be the first to synthesise the findings about the impact on student achievement in mathematics of several approaches to formative assessment.

All of the approaches to formative assessment investigated can be theoretically linked to the definition of formative assessment by Black & Wiliam (2009) through the shared characteristic of adapting teaching and/or learning based on information on student learning needs identified through assessment. The fact that a positive impact on student achievement was found for all approaches indicates that this shared characteristic is a determining factor for the impact. However, this does not mean that all implementation of formative assessment will achieve the same effects or even have any effect on student achievement. Even though the results of this review suggest that formative assessment may be carried out in many different ways to enhance learning, different implementations will naturally provide different effect sizes. In addition, formative assessment that includes the core practice but is not executed sufficiently may not have any effect on student achievement. When speaking about the effect of formative assessment, it is therefore crucial to carefully describe the characteristics of the practice that was implemented.

When reflecting over the size of the effect sizes that are found in the studies in which computer programs were used to generate test information, one may note that the teaching and learning adjustments were facilitated, but also limited, by the computer programs. The teachers obtained help from the programs, but they were limited by not having had training and support to enable them to run, on an on-going basis, the formative assessment process through other approaches and to make the appropriate adjustments in their teaching. Thus, as well as variation of effect sizes resulting from differences in these computer programs, formative assessment based on teachers' adaptation of instruction based on their own frequent assessment may provide different affordances and effects on student achievement.

To get a clearer picture of exactly how formative assessment works to enhance student learning in mathematics, it would be of value to compare how the mathematics is treated in the different approaches to formative assessment. Examples of issues that would be relevant are the types of assessment tasks being used, the kinds of inferences about learning that are being made based on students' responses to these tasks, the kinds of adaptations the teachers make, and the kinds of mathematical thinking these actions bring about in students. Such an analysis is not within the scope of the present review, and many of the articles included in the review do not provide sufficient information for this kind of analysis. However, future studies that describe and compare how the components of the different formative assessment practices work individually and together on a teacher and student level to produce learning would strengthen the theory of formative assessment. It would also support teachers' implementation of successful formative assessment practices.

Identified areas in special need of additional research

There is also a need for additional research in other areas and of other characteristics related to the effects of formative assessment on student achievement. Based on this review, the following needs for research were identified:

1. Studies of the impact of peer assessment

No articles focusing on peer assessment and subsequent actions were found in the literature search, which indicates a shortage of studies focusing on this approach to formative assessment in mathematics.

2. Studies of formative assessment using integrated approaches

As this review shows, most studies focus on individual aspects of formative assessment. The theoretical development of formative assessment has, however, moved towards classroom practice that integrates different approaches to formative assessment into a whole (the fifth approach (e.g. Wiliam & Thompson, 2008). This practice should have the potential to further strengthen student learning. No study in this review investigated the effects of such a holistic view of formative assessment.

3. Studies of high ecological validity

One purpose of mathematics education research is to provide insights that may be of use in teaching practice. Based on this assumption, there is a considerable need for research with high ecological validity, which includes doing studies of normal classroom environments over longer periods. A majority of the studies in this research review are either correlational studies where different variables have been measured on individual occasions, or intervention studies where a specified and well-controlled intervention has been carried out during a relatively short time. These studies are valuable but need to be supplemented with studies that generate insights into how formative assessment can function for ordinary teachers under normal classroom conditions over a long period. This type of study is of central importance in enabling teachers to implement a formative assessment practice based on scientific foundations.

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Notes

1 The review is a condensed version of part of a report written on behalf of the Swedish Research Council (Ryve et al., 2015).

2 The symbol * has the function that all words that can be formed with all possible letter combinations that follow the letters in front of the symbol will be used in the search.

Appendix 1. Articles included in the review

Teacher assessment with subsequent instructional actions

Burns, M. Klingbeil, D. & Ysseldyke, J. (2010). The effects of technology-enhanced formative evaluation on student performance on state accountability math tests. *Psychology in the Schools*, 47 (6), 582–591. doi: 10.1002/pits.20492

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Feedback

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Self-assessment with subsequent actions

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Appendix 2. Information about reviewed studies

Table 2. *Teacher assessment with subsequent instructional actions*

Article	Type of research	PD	Computer program support	Length of interven-tion	Students	Term for formative assessment	Formative assessment component	Measured mathematics achievement	Type of measure of mathematics achievement	Group comparison	Results
Burns et al. (2010)	Intervention	No info	Yes	1–5 years	Elementary	Formative evaluation	Tests, feedback and modified instruction	General mathema-tics achievement	State wide test (reading test as covariate)	vs control	p<.001 ES = .51
				> 5 years	Elementary	Formative evaluation	Tests, feedback and modified instruction	General mathema-tics achievement	State wide test (reading test as covariate)	vs control	p<.001 ES = .78
Koedinger et al. (2010)	Intervention	No info	Yes	1 year	Grade 7	Formative assessment	Tests, feedback and modified instruction	General mathema-tics achievement	Pretest and posttest	vs control	p<.001 ES = .23
					(Special education)	Formative assessment	Tests, feedback and modified instruction	General mathema-tics achievement	Pretest and posttest	vs control	p<.001 ES = .50
					(Regular students)	Formative assessment	Tests, feedback and modified instruction	General mathema-tics achievement	Pretest and posttest	vs control	ns
Phelan et al. (2011)	Intervention	9 hours	No	8 lessons	Grade 6	Formative assessment	Tests, feedback and modified instruction	Understanding of basic mathematical principles	Pretest and posttest	vs control	ns
Yeh (2009)	Review	Various	Yes	Various	Grade K–10	Formative assessment	Tests, feedback and modified instruction	Mathematics problem solving	Pretest and posttest + cost calculation	Formative assessment (FA) vs class size reduction	FA 124 times more cost-effective
	Intervention	Short	Yes	7 months	Grade 2–8	Formative assessment	Tests, feedback and modified instruction	Mathematics problem solving	Pretest and posttest	vs control	ES = .32
	Intervention	1 day	Yes	18 weeks	Grade 3–10	Formative assessment	Tests, feedback and modified instruction	Mathematics problem solving (and reading)	Pretest and posttest	vs control	ES = .39

Table 3. *Feedback*

Article	Type of research	PD	Computer program support	Length of intervention	Students	Term for formative assessment	Formative assessment component	Measured mathematics achievement	Type of measure of mathematics achievement	Group comparison	Results
Brosvic, et al. (2006)	Intervention	No info	Yes	20 sessions	Grade 3	Feedback	Task feedback (correct/not correct)	Numerical fact series	Pretest and posttest	Immediate feedback (from Teacher or Computer) vs Delayed feedback, and control	p<.005
					MLD-students	Feedback	Task feedback (correct/not correct)	Numerical fact series	Pretest and posttest	Immediate feedback (from Teacher or Computer) vs Delayed feedback, and control	p<.005
Cates (2005)	Intervention	NA	Yes	16–20 sessions	Four MLD-students, 8–11 years	Feedback	Immediate task feedback (correct/ not correct)	Numerical facts	Test at each session	Feedback from computer vs from peer	Non-conclusive
Clarke et al. (2014)	Intervention	6 hrs	No	20 weeks	Grade 1, students at risk	Formative evaluation	Feedback and cumulative review	Proximal measure of conceptual understanding	Pretest and posttest	vs control	p<.015 ES=.82
								Distal measure of procedural fluency	Pretest and posttest	vs control	ns
								Distal measure of conceptual understanding	Pretest and posttest	vs control	ns
Dresel et al (2008)	Intervention	NA	Yes	5–9 sessions	Grade 6	Feedback	Feedback	Expected mathematics content for the grade	Pretest and posttest	Attribution feedback vs control	p<.01 ES=.54
Labuhn, et al. (2010)	Intervention	NA	No	<40 min	Grade 5	Feedback	Feedback as graphs showing number of correct answers on groups of tasks	Application of procedures	Pretest and posttest	vs control	ns
Rakoczy, et al. (2013)	Intervention	NA	No	110 min	Grade 9	Feedback	Written process-oriented feedback, social comparative feedback	General mathematics achievement	Pretest and posttest, Pretest and postgain scores.	Process-oriented feedback vs test grades (SEM)	Indirect β=.1795% CI [.06, .33]
Rakoczy, et al. (2008)	Correlational	NA	No	NA	Grade 8–9	Feedback	Evaluative, informational feedback	Conceptual understanding, simple applications	Pretest and posttest	NA	ns
Roschelle et al. (2010)	Intervention	Yes	Yes	12 days	Grade 4	Feedback	Task feedback	Conceptual and procedural knowledge	Pretest and posttest	Group vs individual feedback	p<.05 ES=.22

Table 4. *Self-assessment with subsequent actions*

Article	Type of research	PD	Computer program support	Length of interven-tion	Students	Term for formative assessment	Formative assessment component	Measured mathematics achievement	Type of measure of mathematics achievement	Group comparison	Results
Dignath et al. (2008)	Meta-analysis of intervention studies	Various	No info	Various	Grade 1–6, 7–9	SRL	SAS	Various	Various (Grade 1–6)	NA	ES = .96
									Various (Grade 7–9)	NA	ES = .23
Dresel et al (2008)	Intervention	NA	Yes	5–9 sessions	Grade 6	SRL	SAS	Expected mathematics content for the grade	Pretest and posttest	SRL + attribution feedback vs attribution feedback	ES = .52 p<.05
Kistner et al (2010)	Correla-tion	NA	No	3 lessons	Students 15 years	SRL	Teachers' instruction of SAS	Understand proof	Pretest and posttest	NA	p = .42 r = .47
							Teachers' instruction of SAS	General achievement, knowledge, skills	Pretest and posttest	NA	ns
							Teachers' explicit instruction of SAS	Understand proof	Pretest and posttest	NA	p<.05 r = .52
							Teachers' implicit instruction of SAS	Understand proof	Pretest and posttest	NA	ns
Kramarski & Gutman (2006)	Intervention	5 weeks	Yes	Yes	Grade 9	SRL	SAS	Procedural tasks	Pretest and posttest	SRL+ feedback vs feedback	p<.001 ES = .44
								Math argument	Pretest and posttest	SRL + feedback (posttest vs pretest)	ES = 1.75
										Other treatment (posttest vs pretest)	ES = .77
								Math explanation	Pretest and posttest	SRL+ feedback (posttest vs pretest)	ES = 2.24
										Other treatment (posttest vs pretest)	ES = .46
Kramarski & Mizrachi (2006)	Intervention	NA	Yes	4 weeks	Grade 7	SRL	SAS	Standard tasks	Pretest and posttest	SRL online vs SRL	ES = .50
								Standard tasks	Pretest and posttest	SRL vs non-SRL online	ES = .81
								Real life problems	Pretest and posttest	SRL online vs SRL	ES = .70
Lazakidou et al. (2010)	Intervention	NA	Yes	2 months (10 sessions)	Grade 4	SRL	SAS	Problem solving	Pretest and posttest (different with same structure)	Group compared to itself	p<.01 2.4%
Marchis (2012)	Correlation	NA	No	No info	Students 14/15 – 17/18 years	SRL	SAS	No info	Self-reported grades	NA	r = .3
Metallidou et al. (2010)	Correlation	NA	No	NA	Grade 5,6	SRL	SAS	No info	Teacher survey, scale	NA	p ≤ .001 corr = .78
Montague (2008)	Review	No info	No	No info	Students at risk	SRL	SAS	Various	Overall conclusion	NA	Positive effect
Ness et al. (2012)	Case study, Interven-tion	NA	No	No info	Grade 6, 1 student	SRL	SAS	No info	Grades before and after	Student compared to self	C- to B-
Ocak et al. (2013)	Correlation	NA	No	NA	Grade 5	SRL	SAS	No info	Student grade point average score	No (SEM)	ns
Rosario et al. (2013)	Correlation	NA	No	NA	Students 12–19 years	SRL	SAS	No info	End of term test + marks on homework	No (SEM)	p = .000 r = .43

Notes to tables

ES = effect size
MLD = mathematics learning disabilities
NA = not applicable (e.g. PD-support not applicable when the intervention was carried out by the researchers)
ns = non-significance
PD = professional development
SAS = self-assessment and subsequent actions
SEM = structural equation modelling
SRL = self-regulated learning

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