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Formative Assessment and Teachers' Sensitivity to Student Responses

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Formative assessment, and especially feedback, is considered essential to student learning. To provide effective feedback, however, teachers must act upon the information that students reveal during instruction. In this study, we apply a framework of formative assessment to explore how sensitive teachers are to students' thoughts and ideas when teaching for conceptual understanding. Six elementary school teachers were interviewed and videotaped as they implemented a curriculum that emphasized the teaching of key science concepts through different modes of learning (doing, reading, writing, and talking). We created four main categories for fostering conceptual understanding: identifying learning goals, eliciting student information, interpreting student information, and acting. Findings indicate that elementary school teachers with low levels of pedagogical content knowledge in science do not always know the key concepts of a scientific idea or how to teach them to increase student learning. Therefore, teachers' interpretation of students' responses and their subsequent actions are not likely to be aligned to the scientific idea the key concepts represent. We suggest that teachers need support to identify the key concepts within the discipline of science. Equally important is to realize that to make meaning, these concepts must be taught in a context and in relation to other words within the discipline.

Keywords: *Formative assessment; Conceptual learning; Science and literacy; Classroom study*

Introduction

A vast amount of literature considers that formative assessment is vital to student learning, and the benefits are largely associated with the positive impact of feedback (Bell & Cowie, 2001; Black & Wiliam, 1998; Harlen, 2009; Sadler, 1989). To

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provide effective feedback, however, teachers must act upon the information that students reveal during instruction (Harlen, 2009). Thus, when we examined teachers' instructional practices for promoting and assessing student conceptual understanding in the present study, the main aim was to explore teachers' sensitivity to student thoughts and ideas. Sensitivity is understood as the extent to which the teachers notice and build on features in student thinking related to the scientific idea being taught (Coffey, Hammer, Levin, & Grant, 2011). This is similar to responsiveness, described by Black, Harrison, Lee, Marshall, and Wiliam (2003) as how the teacher clarifies, questions, and probes student utterances in an attempt to understand their thinking.

Several scholars claim that formative assessment is in danger of becoming a strategy focusing more on pedagogical skill than on the content to be taught (Bennett, 2011; Coffey et al., 2011; Duschl, Schweingruber, & Shouse, 2007). The formative assessment literature often assumes that teachers know what to look for in student responses and how to align those responses to the scientific phenomenon investigated (Black et al., 2003; Hattie & Timperley, 2007). Thus, the substance and quality of the teachers' reactions to information that students reveal during instruction is rarely examined or communicated. With this study, we address this absence and build on Coffey et al.'s (2011) critique of a missing disciplinary content of formative assessment.

We followed six elementary school teachers as they implemented an integrated inquiry-based science and literacy curriculum. In this curriculum, science inquiry implies that students search for evidence in order to make and revise explanations based on the evidence found and through critical and logical thinking (Barber, 2009). Furthermore, the curriculum emphasized the learning of a set of pre-selected key science concepts through hands-on (do it) and literacy (talk it, read it, and write it) activities (Cervetti, Pearson, Bravo, & Barber, 2006). It has been well established that learning to use the language of science is vital for learning science (Lemke, 1990; Mortimer & Scott, 2003; Wellington & Osborne, 2001). Several studies highlight that inquiry-based science only fosters conceptual understanding in students when students make use of the language of science to discuss empirical evidence, to connect theory and practice, and to communicate and justify their results (Minner, Levy, & Century, 2010; Ødegaard, Haug, Mork, & Sørvik, 2014; Yore, Bisanz, & Hand, 2003). In Norway, where this study takes place, reading, writing, and talking are highlighted in the science curriculum; not only as a means of constructing science understandings, but also as an essential goal of science literacy (Yore et al., 2003).

Purpose of the Study

With a special interest in teachers' sensitivity to student responses, the aim of this study was to explore and qualitatively describe how teachers promoted conceptual understanding within a framework of formative assessment. To guide our research, we asked the following questions:

- Which features of formative assessment emerge as essential to foster conceptual understanding?
- How does an integrated science/literacy curriculum provide opportunities for promoting and assessing conceptual knowledge?
- How can findings from the present study be transformed into a general model for assessment to support learning in science education?

To help answer the research questions, we collected empirical data through teacher interviews and video-based observations in six classrooms. In the analyses, we focused on the teaching of key science concepts in the integrated curriculum, and used this as a point of reference for conceptual development.

Features of Formative Assessment and Conceptual Understanding

In this section, we present an overview of the theoretical perspectives and literature we draw on when analyzing and discussing the empirical data. First, formative assessment is addressed with an emphasis on feedback, the absence of disciplinary substance, and the role of pedagogical content knowledge (PCK). Then, we provide a brief overview of the theoretical underpinnings for conceptual understanding.

Formative Assessment

Over the last decades, a number of definitions of the term formative assessment have been proposed. In a review of formative assessment, Bennett (2011) argued that existing definitions of the term formative assessment admit such a variety of implementations that effects should be expected to vary widely from one implementation and student population to the next. The perspective of formative assessment applied in this study is supported by many scholars. It puts forth that for formative assessment to take place, teachers must gather and interpret information of students' thinking and then use this information to make instructional decisions for the purpose of helping students toward the learning goals (Black & Wiliam, 1998; Harlen, 2003; Sadler, 1989).

Feedback

A central part of teaching for conceptual understanding is dialog with students to clarify their existing ideas and help them toward scientifically established ideas (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Scott, Mortimer, & Ametller, 2011). This involves providing feedback to students about how their existing conceptions relate to the scientifically accepted ones and helping students to modify their thinking accordingly. Feedback is an essential part of formative assessment, and many educational researchers consider feedback as the most effective aspect of student learning (Bell, 2007; Hattie & Timperley, 2007; Shavelson et al., 2008). Type of feedback, however, is crucial, and evidence from various studies shows that some types of feedback are more effective than others (Black & Wiliam, 1998; Ruiz-Primo & Furtak, 2007). Feedback about the person (usually praise) is least effective (Black & Wiliam, 1998; Butler, 1987; Hattie & Timperley, 2007). Feedback that relates to specific and clear goals and processing of the task (Hattie & Timperley, 2007; Hodgson & Pyle, 2010; Sadler, 1989), focuses on students' ideas (Chin, 2006; Coffey et al., 2011; Harlen, 2003), and offers guidance for improvement (Bell & Cowie, 2001; Black et al., 2003) are beneficial. Feedback can be provided by teacher, peers, or oneself (Bell & Cowie, 2001; Black et al., 2003). In this study, feedback refers to information provided by the teacher to students regarding their responses and ideas, and support provided to improve students' conceptual understanding.

Figure 1 illustrates a model based on our understanding of the theoretical perspectives of formative assessment applied as a guideline for the analysis in this study. The model involves eliciting and interpreting information about students' thinking, and acting on this information by adapting teaching according to students' needs or by providing feedback. There are different ways of acting. One is to modify and adapt whole-class instruction based on student responses, or the lack thereof. For example, by adjusting the level of difficulty or changing the mode of representation to reach more students. Another action is to provide feedback to students, individually or in a group, as a reaction to information gathered on students' thinking. The nature of feedback varies, and in the model there are two types of feedback, confirmative and elaborative. The first refers to confirming student answers, while the latter means to elicit more information and provide guidance and cues to enhance learning. Elaborative feedback is more effective for learning than just indicating whether the students' work is correct or not (Harlen, 2003; Hattie & Timperley, 2007). However, as Mortimer and Scott (2003) argued, there are some 'truths' in science, and sometimes it is necessary for teachers to lead students through a sequence of questions and answers to reach a scientific point of view.

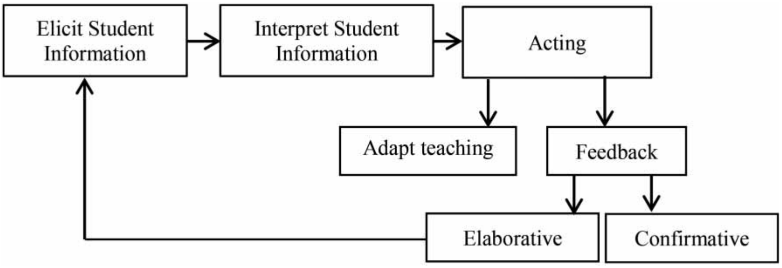

Figure 1. Model based on theoretical perspectives of formative assessment. The model involves eliciting and interpreting information about students' thinking, and acting on this information by adapting teaching according to students' needs or by providing feedback. Confirmative feedback refers to confirming student answers, elaborative feedback means providing guidance and cues to elicit more student information

Missing Disciplinary Substance of Formative Assessment

Several scholars advocate that general practices associated with formative assessment facilitate learning (Bell, 2007; Black & Wiliam, 1998). Even so, Coffey et al. (2011) claimed that formative assessment is treated as strategies and techniques for teachers, and largely disregards the disciplinary substance of what teachers should be assessing. To support this claim, they selected four highly cited publications—Black et al. (2003), Shavelson et al. (2008), Morrison and Lederman (2003), and Bell and Cowie (2001)—and highlighted the lack of attention to student reasoning described in these studies. The critique was directed toward views of content as correct information, and for focusing on strategies that cut across topics and disciplines. Such strategies included wait time or 'stop lighting' (Black et al., 2003) or questioning without closely examining the ideas and reasoning they revealed. Coffey et al. (2011) argued that formative assessment does not promote learning if the teachers consider only the 'gap' between student thinking and the correct conceptual understanding. Supporting students' learning process requires sensitivity to *how* students reason about the natural world.

Pedagogical Content Knowledge

Several scholars agree that teachers' enactment of formative assessment depends on their level of PCK (Ball & Hill, 2009; Bell, 2000; Shepard, 2000). Shulman (1987) has described PCK as the range of knowledge bases that teachers need to successfully teach a subject to a specific group of students in a particular discipline. The relationship between possessing the content knowledge and knowing how to teach this content is found to be especially difficult for elementary school teachers (Ball, 2000; Dixon & Williams, 2003). A suggested explanation is that elementary school teachers are required to teach a number of subjects and typically have less subject-matter knowledge than those teaching at higher levels of schooling (Magnusson, Krajcik, & Borko, 1999). The teacher's level of PCK affects formative assessment in several ways. For instance, teachers with low-level PCK are less likely to know what questions to ask students to elicit their ideas or which conceptual difficulties to anticipate, including students' everyday conceptions of a scientific idea. Furthermore, what inferences to make of student answers and what actions to take to adjust instruction toward scientifically accepted ideas require a certain level of PCK (Ball & Hill, 2009; Bell, 2000; Harlen & Holroyd, 1997). In addition, Black and Wiliam (1998) stated that formative assessment is not well understood by teachers and is weak in practice. Several studies show that teachers need substantial knowledge, time, and support to implement formative assessment effectively in classrooms (Bell & Cowie, 2001; Bennett, 2011; Shavelson et al., 2008). Considering the connection between PCK and formative assessment discussed in the literature, the teachers' level of PCK is central in our analysis of how to teach for conceptual understanding within a framework of formative assessment.

Teaching for Conceptual Understanding

The participating teachers in this study implemented an integrated science/literacy curriculum in which students engaged with key science concepts multiple times through multiple modalities (do it, talk it, read it, and write it) (Cervetti et al., 2006). To support the development of conceptual knowledge, Cervetti et al. (2006) stressed the importance of teaching key science concepts in a context and together with other related words. The context could, for example, be the students' own investigations of making glue, together with exploring the concepts of material and property from a supportive text. This is consistent with the framework for word knowledge described by Bravo, Cervetti, Hiebert, and Pearson (2008). Central to this framework is Vygotsky's (1986) idea that the development of concepts and the development of word meanings are the same process. From this point of view, language development and conceptual development are inextricably linked and conceptual knowledge develops alongside an increased understanding of word meaning. In traditional science instruction, concept learning is sometimes reduced to acquiring the definitional knowledge of a large number of words (Cervetti et al., 2006). In Bravo et al.'s (2008) framework, the definitional level serves as a starting point for the development of conceptual understanding, not the end. Conceptual understanding requires that students are able to situate the word in a network of related words and ideas, apply it in relation to their own experiences, and use the word in their oral and written communication. This perspective of conceptual development was used to analyze how the teachers scaffold students' conceptual understanding through formative assessment. The key science concepts emphasized in the integrated curriculum served as learning goals as these concepts are considered essential to develop conceptual understanding of the phenomenon being taught.

Methods

In the Methods section, we first present the context of the study, including a detailed description of the teaching material implemented. Then, the participating teachers are introduced before we discuss the data collection procedures and the data sources. Finally, we give a thorough explanation of our analyses.

Context of the Study

The study takes place in Norway and is part of a larger project aiming to test and refine a teaching model that integrates inquiry-based science and literacy, the Budding Science and Literacy project (Ødegaard, Frøyland, & Mork, 2009). This project builds largely on curriculum materials from the teaching program *Seeds of Science/Roots of Reading*[1] (Seeds/Roots) developed at Lawrence Hall of Science, Berkeley. Included in this program is systematic and detailed curriculum material, introducing a do it (hands-on), talk it, read it, and write it approach to science teaching and learning. The focus on inquiry and literacy skills is in line with the Norwegian National

Curriculum[2] that emphasizes inquiry-based science and integration of reading, writing, and talking in all subjects, including science. The Budding Science and Literacy project invited elementary school teachers to participate in a professional development (PD) course focusing on integrating inquiry-based science and literacy. As part of the course, the teachers implemented and adapted teaching materials from Seeds/Roots to the local context of their classrooms (e.g. language, students' age, time and tools available, national curriculum, school policies). Six teachers from four different schools volunteered to be interviewed and videotaped before, during, and after the implementation. Before the data collection, the participating teachers, parents on behalf of the underaged students, and the principals signed an informed consent form agreeing to the videotaping of classroom instruction for research purposes. All names in the study are pseudonyms.

Teaching Material

The Seeds/Roots curriculum the participating teachers implemented consisted of a number of units covering life science, physical science, and earth science topics. All the Seeds/Roots units rest on the principle of integrating inquiry-based science and literacy and focus on a set of pre-selected key science concepts (Cervetti et al., 2006). Key concepts consist of words that are central to science and necessary for understanding the scientific ideas (e.g. force, gravity, property, and system), and the processes (e.g. investigate, data, and evidence) being taught. Every unit included a detailed step-by-step teacher guide with instructional strategies and embedded assessment. The teacher guide provided examples of what to expect from students at specific stages in the unit. For example, in a unit called *Gravity & Magnetism*, in which two of the key concepts were *forces* and *evidence*, the guide stated, 'Students should now be able to identify a variety of pushes and pulls from the pictures in the book as evidence of forces.'[3] It also offered suggestions for how to provide more experience and support if necessary, e.g. 'If students struggle help them to locate evidence of forces, and encourage them to ask themselves if they see a pull happening in this page, or a push.'[4] Additionally, there were investigation notebooks for the students that teachers could use to collect evidence of student learning. The teaching materials were designed to help teachers apply entire cycles of inquiry. This involved teaching students how to ask researchable questions and conduct investigations to search for evidence that can help answer their questions.

Participants

Six teachers volunteered for this study (Table 1). They were all part of a cohort of 22 elementary school teachers attending a year-long PD course with monthly meetings. The course focused on lectures and practice related to the integration of inquiry-based science and literacy in the classroom. As part of the PD course, the teachers selected sessions from a Seeds/Roots unit of their choice to teach in their classroom. None of the teachers had specialist science qualifications; they were generalists

Table 1. Background information for participating teachers (pseudonyms)

School	Teacher	Grade (age)	Years of teaching experience	Number of students	ECTS credits in Science[a]
A	Anna	5 (10–11)	0–5	14	16–30
B	Betsy	1 (6–7)	11–15	18	16–30
B	Birgit	4 (9–10)	11–15	24	16–30
C	Cecilia	3 (8–9)	20+	19	16–30
E	Ellinor	3 (8–9)	11–15	16	31–60
E	Emma	3 (8–9)	20+	21	16–30

[a] The generalist teacher training includes between 16 and 30 ECTS credits in science. Thirty credits are equivalent to a 6-month course.

teaching all subjects in elementary school (6–12 years old). Years of teaching experience varied among the teachers, from a novice in her second year of teaching, to experienced teachers with more than 20 years of practice (Table 1). There were only female participants at the course, which is not surprising since approximately 90% of elementary school teachers in Norway are women.[5] The typical participant attended the course with one or several colleagues from the same school, as intended by the course developers to create opportunities for the teachers to cooperate locally. All the schools were located within two neighboring counties with comparable conditions regarding resources for schooling and socio-economic status. The students were mainly ethnic Norwegians.

Data Collection and Data Sources

To answer our research questions, we collected empirical material through multiple qualitative data collection methods (Denzin & Lincoln, 2000) (Table 2). Individual

Table 2. Data collection and data sources

Unit of analysis	Data sources	Timing	Participants (*N*)
Description of science teaching practice	Interviews	Pre- and post-implementation	6
	Questionnaire	Pre-implementation	22
	Written reflections	Post-implementation	22
	Paper/ presentation	Post-implementation	22
Enacting science teaching	Video recordings	During implementation	6
Sensitivity to student responses	Interviews	Pre- and post-implementation	6
	Video recordings	During implementation	6

interviews conducted with the six teachers (Table 1) provided the main source of data. This was supplemented by videotaped classroom observations of the six teachers' implementation of the integrated curriculum material. In addition, we had access to data provided by all 22 participants in the PD course. In the beginning of the course, the teachers responded to an open-ended questionnaire regarding their current approaches to science teaching. At the end of the course, the participants submitted reflection notes and course papers. They also agreed to be videotaped during an oral presentation of their experiences with the implementation process. These sources were used as supporting data and compared to findings from the interviews.

The six teachers were interviewed twice, first in the early part of the PD course, and then again within a few days after they finished implementing the teaching material. This ensured that the implementation process was still fresh in mind. Since the interviewers (the authors) were present in the classroom during implementation, there was a common understanding of references made by either the interviewer or the interviewee. We developed and applied a semi-structured interview guide for the interviews, which lasted between 40 and 55 minutes each. The first interview invited the teachers to reflect upon their daily practice regarding strategies for promoting and assessing science concepts, and especially their sensitivity to student responses. The second interview focused on the same, with an emphasis on the implemented teaching material.

The purpose of the video recordings was to more clearly understand what was happening in the classroom and to confirm the consistency between teachers' saying and doing. Two cameras in the classroom provided data for this study: One small wall-mounted camera faced the students, and one camera followed the teacher. The videos were supplemented with audio recordings. Altogether, there are 35 hours of video recordings evenly distributed among the six teachers.

Analysis

The analysis was guided by our research questions and the overarching aim of exploring teachers' sensitivity to student responses when promoting and assessing conceptual understanding. Transcripts from the interviews formed the bases for our analyses, while segments from the additional data sources were included when applicable, informing the study and establishing credibility. The triangulation of data sources and analyses ensured rich, robust, and comprehensive data that allowed us to check for consistency and, equally important, inconsistency in the findings (Denzin & Lincoln, 2000). Various analyses were applied to the data retrieved from the interviews and videotapes, which elucidated several aspects of the same phenomena and contributed to enhance the study's credibility (Berkowitz, 1997; Bogdan & Biklen, 2003).

Drawing on theoretical perspectives on formative assessment, we read and reread the interviews to search for emerging themes that might help us to understand different aspects related to the teachers' instructional practice. To capture the respondents' thoughts about their teaching practice, we used some of their own phrases to label codes in the initial coding process, as suggested by Bogdan and Biklen (2003). This could be common topics emerging in responses about specific matters, for example, codes regarding formative assessment of student understanding such as 'I listen when students discuss' or 'I believe they understand'. Then, codes for similar content were grouped into new codes created to highlight information on teaching practices, including sensitivity to student responses and level of PCK. Finally, these codes were adapted into overarching categories in an iterative process moving in and out between the data sources and analysis until redundancy (Strauss & Corbin, 1994) (see Table 3 for codes and categories). The categories were systematically applied to each interview transcript and additional data sources when applicable (questionnaire, reflection notes, course paper, and transcript of teacher presentations). Due to the study's design and to answer the research questions, we distinguished between teacher responses referring to before and after the intervention within each category. The intervention was the PD course including the implementation of the integrated curriculum.

The next move was to look for patterns within each category, and how these patterns, or lack thereof, could help illuminate our questions (Berkowitz, 1997). Analyzing the transcripts from interviews, written papers, and presentations did not provide sufficient data on teachers' sensitivity to student responses during instruction. Therefore, we went to the video recordings to see what instruction looked like from a classroom perspective. To reduce the workload of going through countless hours of video to select episodes for analysis, we based our selection on available information, as recommended by Derry et al. (2010). From the teacher guides, we first identified embedded assessment points connected to assessing students' understanding of science concepts, and then we located the corresponding events in the video material. We also used events discussed in the interviews as a guideline to inform the search. Four teaching sequences were eventually considered representative and significant to inform the study.

Findings

When analyzing the interviews, we identified several codes describing practices linked to promoting and assessing student conceptual understanding (Table 3). Based on these codes, we created four categories labeled: *Identifying learning goals*, *eliciting student information*, *interpreting student information*, and *acting*. These categories are thoroughly described in the following subsections.

Findings from the analysis of pre- and post-intervention data are presented to elucidate changes in teachers' instructional practice. Worth noting is that teacher statements across the different data sources (interviews, reflection notes, papers/presentations) were consistent regarding instructional practice before trying out the integrated science/literacy curriculum as well as after. To provide additional information on the teacher practices linked to the curriculum implementation, we present four excerpts from the transcribed video recordings. The excerpts

Table 3. Codes for teachers’ description of their practice prior to and after the intervention, illustrated with examples and grouped into overarching categories

Category	Description	Codes	Examples pre-intervention	Examples post-intervention
Identifying learning goals	Involves how teachers select words and concepts to teach, and on what they base their selection	Selecting concepts to teach	‘Words that pop up in a conversation or in a text, words that I don’t think they understand’	‘The pre-selected key concepts help me know what they need to learn in order to understand the things we are discussing’
		Teachers’ presuppositions of students’ prior knowledge	‘I know what my students know’ ‘If they don’t understand, they ask’	Not addressed
		Teachers’ PCK	‘Concepts are important in science’ ‘It is a little bit hard in science (to select key concepts) since I don’t know science that well’	‘Often there’s a jumble of concepts in textbooks, and I don’t know if they are equally important, so to know which words to focus on was really helpful’
Eliciting student information	Involves teachers’ description of activities to make student thinking and understanding visible, and how this is applied	Activities to make student thinking visible	‘When they talk, they reveal what they know’	‘I notice what students know when they discuss in groups or whole class’
			‘The best, and maybe only way, to collect information on what students know is a written test’	‘The writing activities revealed what the students understood’
		Teacher/student focused	‘I ask them to discuss’ ‘I ask them questions when I summarize the lesson’	‘The students demonstrated what they understood, especially through the written tasks, but also when they discussed their findings’
		Teachers’ PCK	‘Sometimes when they start to ask questions I feel insecure’	‘When I know what is important to learn, the core, then I can open up for all kinds of ideas, because I know how to guide them back on track’

(*Continued*)

Table 3. Continued

Category	Description	Codes	Examples pre-intervention	Examples post-intervention
Interpreting student information	Information about how teachers make sense of the information students reveal, and what kind of information they are looking for	Student responses	‘I’ve been a teacher for so many years, so I just know, like, the way they talk and the way they act’	‘When students discuss in groups, I observe how they apply the key concepts’
		Teachers’ presuppositions of student understanding	‘It’s more like a gut feeling’ ‘I can tell if they understand based on their body language’	Not addressed
		Aligned to learning goals	‘In math and language arts, there are specific goals, it would be easier if we had the same in science’	‘If students use the key concepts in their talk, I consider it as reaching the learning goal’
Acting	Involves teachers’ descriptions of how they provide feedback and adapt their teaching based upon elicited and interpreted student information	Feedback	‘I often ask them to explain what they mean’ ‘It’s important to provide positive feedback to motivate the students’	‘I give them feedback to let them know they did a good job’
		Adapt teaching	‘In math, I know the answer and where to lead the students. It is harder in science where the answer can be almost everything, well, not everything, but much more than I know and can explain’	‘They don’t always get it right the first time, so I have to help them say it the right way’
		Aligned to learning goals	Not addressed	‘I know which students to ask to get the answers necessary to move on’

demonstrate single events, but represent examples of several observations. Results from the interviews are organized in Table 3, while results from the video recordings are described in each subsection. We summarize the findings at the end of the section.

Identifying Learning Goals

The first category, *identifying learning goals*, refers to recognizing the key science concepts necessary for conceptual understanding of the phenomenon being taught. We examined teachers' practice when they selected which concepts, or science words, to emphasize, and how these words were taught to make sense of their meaning. Teachers spoke openly about their lack of a specific approach when teaching science concepts before the intervention, even though they acknowledged the importance of learning concepts in science and in other subjects. The selection of words to accentuate and explain was more or less random, and mainly based on teachers' presupposition of students' knowledge (Table 3). The key science concepts were not identified by the teachers as learning goals. Thus, the words and concepts students need as guidance to conceptual understanding were not explicitly addressed or communicated to the students, something the literature refers to as essential for learning (Harlen & Holroyd, 1997; Lemke, 1990). After the intervention, the teachers expressed that the pre-selected key concepts highlighted in the curriculum contributed to an improvement of their teaching practice. The set of pre-selected concepts provided a direction that helped both the teacher and the students to focus on the core of the scientific idea being taught. The key concepts were clearly recognized as learning goals by the teachers. They knew what to address and what to assess; thus, they were more confident and found it easier to support student learning.

We examined the video recordings to collect more information on the teachers' practice regarding teaching of key science concepts. The selected excerpt is from a lesson in a third-grade classroom (8-year-olds). The unit taught was *Designing Mixtures,* and key concepts introduced included *properties, materials,* and *substances.* In the previous lesson, the students read a book about materials and their properties, and they combined different materials and properties in a written task. Now the teacher has gathered the students to discuss what they have learned so far. At this point in the unit, the teacher guide states that students should be able to connect the properties of an object to the material it is made of.

Excerpt 1

Teacher Emma (T):	Do you remember what properties were? What could properties be?
Maya:	How it smells
T:	Yes, let's take that first (writes 'smells' on the flip chart)
Christian:	Feels
T:	Feels, yes (writes). You remember a lot, I'm impressed. (Listing of different properties goes on for a couple of minutes).

T: Ok, and what was material? What did that mean? Do you remember, John?
John: Like rubber?
T: Yes, rubber could be a material. But what is a material? Ida.
Ida: It is what things are made of.
T: Yes, what things are made of. Do you remember any materials? Dina.
Dina: Metal.
T: Yes (writes metal on the flip chart). Thea
Thea: Iron
(After suggesting some more materials, the students go back to their seats for another task.)

Although students were expected to make links between the key concepts materials and properties, the teacher never requested such links. The students were not challenged to connect the properties of an object to the material it was made of. Which key concepts to focus upon was identified and communicated to the students, but the concepts were addressed only at a definitional level, and thus, conceptual understanding was not supported. The excerpt shows that the key concepts were interpreted and taught as isolated science words and not as part of a network of related words and concepts as required for conceptual understanding (Cervetti et al., 2006; Vygotsky, 1986).

Eliciting Student Information

The second category, *eliciting student information*, consists of activities teachers applied to make student thinking visible. When talking about eliciting student information before the intervention, the teachers mainly emphasized the pedagogical activities they orchestrated, and not what these activities led to in terms of disclosing student thinking. The activities most commonly referred to involved student discussions and questioning to check what the students recalled of the topic addressed (Table 3). Among the teachers, classroom talk was a preferred method for observing students' use and understanding of new science words. However, a written test was considered the best, and, for some, the only way to collect information that provided valid information on student learning (Table 3). According to Harlen and Holroyd (1997), using tests instead of trusting their own observations of students' learning process and the products of their thinking is typical for teachers with low confidence in a subject. After trying out the integrated science/literacy curriculum, teachers emphasized the increased opportunities to observe students' thinking provided by the different modes of representation (do it, read it, write it, and talk it). Except for a few still focusing on *measuring* students' understanding (e.g. thumbs up/down and summative tests), the teachers now accentuated how learners demonstrated their understanding when engaging in hands-on activities, discussions, presentations, log-writing, and so on.

When studying the video recordings, we found several examples of students revealing their understanding as they engaged in different activities. However, the teachers did not always grasp these opportunities to enhance student learning. An example of this is provided in the following excerpt from a fifth-grade classroom (10-year-olds). The unit taught was *Gravity & Magnetism* in which one of the key concepts was *force*. In the selected excerpt, the students were engaged in a hands-on activity exploring how forces act between two objects as a push or a pull. The students worked in groups using blocks with hooks, a spring, and a rubber band. The teacher circulated between the groups.

Excerpt 2

Teacher Anna (T): Has this group thought about how to do it without using the hooks? (Students show by putting the spring between the blocks, push, and let go).
T: Yes. And what kind of force was that an example of? Push or pull?
Thor: Was it a push?
Liv: It was a push or a pull.
T: (Takes the blocks and push them together with the spring in between). If you do like this and want to have the blocks closer? (Teacher walks away).

This activity revealed that the students were confused about how push and pull relate to the concept of force. When the teacher asked what kind of force they observed, the students just guessed. The teacher did not follow-up the student information she elicited and left the students without any further actions. We recognized from the videos what the teachers stated in the interviews; that the do it, talk it, read it, and write it approach provided access to student thinking. However, initiating activities without acting upon the student information they produce do not promote student understanding. Instead, the activities become what Bennett (2011) and Coffey et al. (2011) denoted as merely pedagogical activities without any substance.

Interpreting Student Information

Within the category *interpreting student information*, we grouped the teachers' statements based on how the teachers made sense of student responses, and what kind of information they looked for. Overall, the teachers found it difficult to articulate how they interpreted student understanding. Especially in the first interview, the majority of teachers referred to their long experience as teachers when explaining how they assessed student understanding. They based their judgment on students' body language and behavior, and what they called 'more like a gut feeling' (Table 3). This is consistent with what Bell and Cowie (2001) found in their study; formative assessment is largely a tacit process, and teachers cannot explicitly describe how they do it. When implementing the integrated curriculum, the teachers found multiple opportunities to assess students' understanding. They accentuated the whole-class and group discussions and the written tasks connected to the hands-on activities as valuable for assessment purposes. Furthermore, the key concepts highlighted in the curriculum served as a guideline for what to look for in student responses.

We reviewed the video recordings to collect additional data on how the teachers interpreted student information. Since it is impossible to directly observe what teachers are thinking, our findings were based on how the teacher built on information that students revealed on their thinking related to the key science concepts highlighted in the curriculum. This is exemplified in an episode from a third-grade classroom (8 years old). The unit taught was *Variation and Adaptation* and the key concepts introduced included *variation, adaptation*, and *characteristics*. In the selected excerpt, the teacher invited students to share their findings after working in small groups looking for variation in six different birds depicted on cards. According to the embedded assessment in the teacher guide, at this point in the unit students should be able to describe differences and similarities between organisms and link this to where they live and what they eat.

Excerpt 3

Teacher Cecilia (T): What differences did you see, or observe? (many students raise their hands)
Emma: One is big, and one is small.
T: Yes. Different sizes. Daniel.
Daniel: This is an eagle and this one . . .
T: This one with red breast?
Daniel: Yes. It is that this one is bigger, and this one is smaller, and this one eats like . . . worms, and beetles . . . .and this one eats birds.
T: Yes. You think it looks like that because of the beak? Yes. Ella.
Ella: Different shapes
T: Yes. Different shapes.
(It continues with students identifying different colors, sizes, and shapes.)

Students identified variations in birds, and Daniel attempted to explain why the different birds have different beaks and link this to what they eat. His response was not interpreted or accentuated by the teacher as a step toward conceptual understanding of variation and adaptation. The teacher did not ask Daniel to elaborate, she just briefly summarized what she thought he meant. In this talking activity, students revealed what kind of differences they observed and whether they made any links between variation and adaptation. The activity provided insight into student thinking with ample opportunities for feedback to further the students' understanding. However, the teachers did not recognize, or at least did not address, features in student thinking that provided opportunities to scaffold students' conceptual understanding. Responses of varying quality were accepted on the same terms with no elaboration or further comments. This lack of attention to student reasoning is the core of Coffey et al.'s (2011) critique of how formative assessment becomes a strategy that ignores the disciplinary substance of the idea being taught.

Acting

There are different ways the teachers can act upon the elicited and interpreted student information. In the category labeled *acting*, we looked at action in the form of adapting teaching according to students' needs, and feedback to the students.

All the participating teachers regarded feedback an important aspect of teaching and learning. They often asked the students to explain their thinking, but the feedback provided was mostly in the form of praise to motivate the students and not primarily to elaborate on students' thoughts and ideas. When asked how the assessment information guided further actions, it was challenging for the teachers to find examples from science instruction. Especially in the pre-implementation interviews, several teachers turned to mathematics for examples on how they modified their teaching and provided feedback to promote learning (Table 3). Bell (2000) pointed out that not knowing what inferences to make of student responses or what actions to take to adjust instruction toward the scientific accepted ideas indicate a lack of PCK in science. Several scholars emphasize that effective use of formative assessment requires a certain level of PCK (Ball & Hill, 2009; Harlen & Holroyd, 1997; Shepard, 2000).

After the implementation, the teachers accentuated the increased access to student thinking. This, however, was not used for further action other than praise, the least effective type of feedback for student learning (Black & Wiliam, 1998; Butler, 1987; Hattie & Timperley, 2007). The teachers said they often took pieces of information from student responses that were close to what they were looking for and adapted this to the 'correct' answer. Furthermore, when the teacher guide suggested to check for understanding after a specific activity, the teachers usually asked two or three students, often identified as knowledgeable, to get the answers necessary to move on. This focus on what teachers do, instead of what they see and notice in student understanding, concurs with Coffey et al.'s (2011) critique of the absence of attention to the disciplinary substance. It also indicates a focus directed toward the progress of the class through the curriculum rather than students' needs (Bell & Cowie, 2001).

To confirm the results from the interviews, we examined the videotapes from the classrooms. The selected episode is from the same fifth-grade classroom (10-year-olds) as in Excerpt 2. The unit taught was *Gravity & Magnetism* and key concepts introduced included *forces*, *claim*, and *evidence*. The class had read a book with illustrated examples of forces acting as push and pull between two objects. Throughout the reading, the teacher stopped at each page and discussed evidence of forces at work with the whole class. Following the teacher guide, students should now be able to identify and demonstrate an understanding of forces as pushes and pulls acting between objects.

Excerpt 4

Teacher Anna (T):	Can any of you (reads from the white board): Provide an example of forces acting between two objects, and evidence for your claim? Do you remember some of the things we read in the book? (No one raises their hand, and after a couple of seconds, the teacher continues.) For example, on the soccer field, how do forces act between two objects there? Ina.
Ina:	If the ball comes toward you, then you can kick it, and it changes its direction (depicted in the book).

T:	Mm. Then we have evidence for forces acting between the ball and the leg. Do you recall anything else? Max.
Max:	Balloon and hair (depicted in the book and demonstrated by the teacher).
T:	Yes. Balloon and hair. The hair moves toward the balloon without them touching each other. And what is that force called? Magnus.
Magnus:	Electrostatic force.
T:	Yes.

The example shows how the teacher took bits and pieces from student answers and turned them into the correct phrase she was looking for. She was attentive to the responses but transformed them in a way that made the meaning quite distinct from what the students said. Coffey et al. (2011) referred to this as accentuating the wording instead of the substance of ideas, when a right answer becomes the target instead of focusing on student reasoning. Other episodes from the video recordings supported what we found in the interviews: The feedback provided was confirmative, and it was the curriculum, not student understanding, that decided when to move on to the next topic.

Summary of Findings

When comparing pre- and post-interviews, the teachers expressed an increased emphasis on the key concepts and on students demonstrating their understanding after the intervention (Table 4). Before the intervention, the teachers' attention revolved more around their own instruction and what they as teachers were doing. The teachers described their teaching as aligned to learning the key science concepts in the implemented curriculum. However, video observations revealed that the key concepts were often taught in isolation and not linked to other words and concepts, which is considered necessary for conceptual understanding (Cervetti et al., 2006; Vygotsky, 1986).

Based on our empirical findings, we modified the model of formative assessment as depicted in Figure 1. The modified version (Figure 2) builds on the four categories created from the analysis of teacher interviews. In addition, the figure illustrates what we observed in the classrooms; teachers identified the key concepts as learning goals, elicited student information, and interpreted the elicited information. Teachers' interpretation of student responses, however, was not aligned to the learning goals, which involved an understanding of the identified key concepts. It is not possible to directly observe teachers' thinking; thus, our result was based on the teachers' further actions. There were very few observations of teachers adapting their teaching when students revealed a lack of understanding. Additionally, feedback as praise dominated, and sometimes no feedback was provided at all.

Table 4. Summary of findings from interviews and video recordings organized according to the categories identified

	Experienced by teachers		Observed by researchers
	Interviews		Video recordings
	Pre-intervention[a]	Post-intervention[a]	During implementation
Identify learning goals	No specific approach when selecting science words to accentuate	Pre-selected key concepts	Pre-selected key concepts, taught as isolated words, not concepts
Elicit student information	Focus on what teachers do. Written tests are considered the best way to gather assessment information	Focus on what students disclose. Student thinking made visible when engaging in different activities	Focus on what students do. Student thinking partial displayed through the different activities
Interpret student information	Often based on students' body language and teachers' 'gut feeling'. Not aligned to learning goals	Based on information elicited through activities. Aligned to learning goals (key concepts)	Based on information elicited through activities. Not aligned to learning goals (key concepts)
Acting	Confirmative feedback, mostly in the form of praise to motivate the students	Confirmative feedback, mostly praise	Little or no action taken to elaborate student thinking or adapt teaching. Confirmative feedback, praise

Note: The interviews represent the teachers' voice and the video recordings are observations made by the researchers.

[a] Intervention means the PD course, including implementation of an integrated inquiry-based science and literacy curriculum.

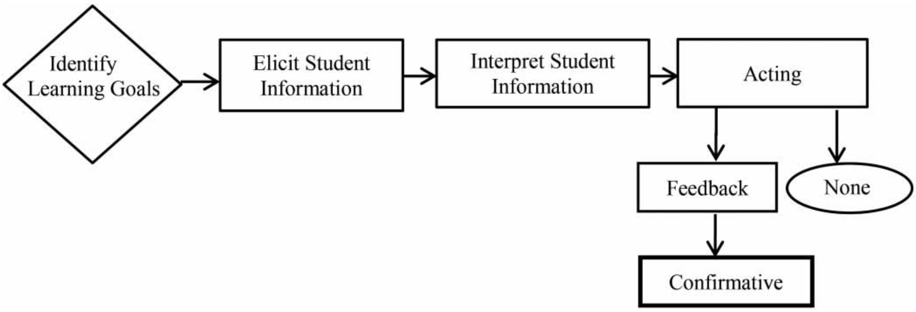

Figure 2. A modified version of the formative assessment model based on observations in the classrooms. The teachers identified science key concepts as learning goals, elicited and interpreted student information. Teacher responses were confirmative feedback or none at all

Discussion

We start the discussion concentrating on essential features of formative assessment necessary to promote conceptual understanding. Second, we discuss changes the teachers experienced in their practice as a result of implementing the integrated science/literacy curriculum. Finally, based on our findings and theoretical perspectives of formative assessment, we present a model linking central building blocks of the assessment process to student learning.

Essential Features When Teaching for Conceptual Understanding

The four categories identified as essential for promoting and assessing conceptual understanding are *identifying learning goals*, *eliciting student information*, *interpreting student information*, and *acting* upon the elicited and interpreted student information. The process in which teachers gather and use information on student learning to make instructional decisions is essential within formative assessment. However, few authors explicitly point to the need for *teachers* to identify and interpret the learning goals to support students' learning processes. We suggest that it cannot be implicitly assumed that elementary school teachers immediately know the key concept of a scientific idea or how to teach it. This suggestion is based on findings from this study and related research addressing elementary school teachers' low level of content knowledge and PCK (Ball & Hill, 2009; Bell, 2000; Harlen & Holroyd, 1997). Without an articulate understanding of what the key concepts are, and how to address and assess them, formative assessment cannot be expected to promote learning or increase student understanding. Thus, one implication of our findings is that teacher educators, curriculum developers, PD courses, and textbook authors need to support elementary school teachers to identify the key concepts within the discipline of science. Equally important is to realize that merely knowing which concepts to teach is not sufficient to promote conceptual learning. To make meaning, the concepts must be taught in a context and understood in relation to other words and concepts. Learning science words one-by-one the traditional way, as exemplified in Excerpt 1, only limits the possibilities to foster deeper understanding of science concepts (Cervetti et al., 2006).

The second key feature identified is *eliciting evidence of learning*. Gaining access to students' thinking to clarify their existing ideas is a central part of teaching for conceptual understanding (Bell, 2007; Driver et al., 1994). Findings presented in Excerpts 2 and 3 in this study indicate that the teachers design opportunities to gather evidence of student learning. However, to support conceptual learning, the activity of eliciting student information must have an explicit rationale. If the information sought is not aligned to the learning goals and if teachers do not engage in the substance of students' ideas, the strategies become more an end in itself than a means to an end. Several authors (Bennett, 2011; Coffey et al., 2011) claim that the literature primarily discusses strategies and techniques for *how* to elicit student information, rather than focusing on *what* is being elicited. The activity of eliciting is not sufficient to promote or assess students' conceptual learning.

To promote conceptual learning, teachers need to interpret the information they collect on student thinking during instruction, represented by our third category; *interpreting student thinking*. This involves making sense of student responses and aligning them to the learning goals, which relates to learning key science concepts in this study. Furthermore, it includes an awareness of the instructional actions required as a response to the interpreted information. Some of the challenges we observed among the teachers were linked to their understanding of teaching science concepts in relation to other words and concepts. This is demonstrated in Excerpt 1 where properties and material were taught in isolation and in Excerpt 3 where the teacher never linked variation in birds to adaptation. When the key concepts are taught only at a definitional level, teachers' interpretation of students' responses and their subsequent actions are not likely to be aligned to the scientific idea the key concepts represent. Therefore, how the key concepts of a scientific idea interrelate must be clearly stated and operationalized in the curriculum. This finding adds on to what is already suggested by many researchers. Teachers with a low level of content knowledge in science require support for recognizing evidence of understanding in student responses (Bell, 2000; Harlen & Holroyd, 1997; Shepard, 2000).

The final main feature identified to support conceptual learning is *acting* upon the elicited and interpreted information. This is considered as the central aspect of formative assessment, and the typical action is feedback from teacher to students (Bell & Cowie, 2001). In the interviews, the teachers reported that providing feedback was primarily undertaken as an act to motivate students, which is consistent with findings by other authors (Black & Wiliam, 1998; Butler, 1987). To support conceptual understanding, scholars advocate that feedback must be related to specific and clear goals, focus on student ideas, and offer guidance for improvement (Harlen, 2003; Hattie & Timperley, 2007). This is an additional evidence for why teachers' identification of learning goals is crucial when assessing and promoting conceptual knowledge. The nature of feedback necessary to support student learning requires knowledge of the idea behind the learning goals. Our findings also show that the integrated curriculum provided access to the students' level of understanding. However, as exemplified in Excerpt 2, the teachers did not always act on this information. Feedback is considered the single most effective aspect of student learning; therefore, an important opportunity for promoting students' conceptual understanding is lost when feedback is omitted. Other studies found that although teachers can make reasonable inferences about student understanding, they face difficulties in making appropriate instructional moves (Heritage, Kim, Vendlinksi, & Herman, 2009; Shavelson et al. 2008). A suggested explanation is that these teachers lack the necessary pedagogical techniques or content knowledge to sufficiently challenge and respond to the students.

Changes in Teaching Practice with the Integrated Science/Literacy Curriculum

From the teachers' point of view, there were two aspects of the integrated science/literacy curriculum that contributed to major changes in their teaching practice. First, the pre-selected set of key concepts serving as learning goals, and second, the increased access to student thinking as students engaged in different activities (doing, reading, writing, and talking) (Table 4). With a pre-selected set of key concepts acting as guidelines, the teachers stated that they felt more confident when teaching science. They experienced that the curriculum provided important support. Such support is recommended in several studies and considered necessary for teachers with low-level content knowledge (Ball & Hill, 2009; Bell, 2000). Teachers also emphasized how the variation of modalities suggested in the integrated curriculum made student thinking visible, thus easier to assess. From the pre- to the post-intervention interviews, we saw that the teachers' emphasis shifted from concentrating on strategies associated with eliciting information to the information students disclosed when engaging in the different activities. The shift of emphasis alone was not sufficient to promote conceptual understanding; however, it was an improvement of the teachers' assessment practice. These findings concur with studies showing that increased teacher confidence in a particular subject is linked to the teachers' ability to assess students' learning (Harlen & Holroyd, 1997).

Nevertheless, our findings indicate that the teaching material, including the embedded assessment, is necessary but not sufficient. The video recordings revealed that the key science concepts were not promoted or assessed in ways required to foster conceptual understanding. In addition, the teachers did not use the improved access to student thinking to provide feedback or adapt teaching to students' needs. There are few observations in the video material of students demonstrating evidence of conceptual understanding expressed by interlinking of key concepts and applying new knowledge in relation to their own experiences. Just as Shavelson et al. (2008) argued, simply embedding assessment in curriculum does not automatically lead to student learning.

Last, when comparing teachers' saying and doing as presented in Table 4, we see that teachers experienced that their teaching was aligned to the learning goals while the video recordings revealed a different result. These findings suggest that teacher educators, professional developers, and researchers cannot assume that pre-service and in-service teachers who use the expected vocabulary to describe their practice actually understand and can enact the practice.

Model of Assessment to Promote Learning

We started out this study with a theoretical framework of formative assessment (Figure 1), which we modified according to our empirical data (Figure 2). Then, based on theoretical perspectives of formative assessment and our empirical findings, we designed a general model of assessment to promote conceptual learning (Figure 3). The model includes possible pathways dependent on teachers' action. We emphasize that the first step, labeled *identifying and interpreting learning goals*, is essential for fostering conceptual knowledge. This step is often under-communicated in formative assessment studies. Though many point to the necessity of communicating the learning goals to the students (e.g. Harlen, 2003), teachers' identification and interpretation of these goals do not receive the same attention.

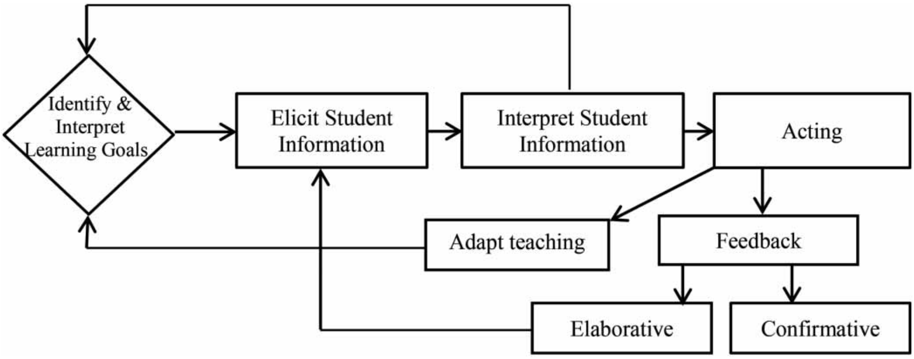

Figure 3. Model based on empirical data and principles of formative assessment. The assessment process is viewed as an iterative one, moving back and forth between the different building blocks indicated by arrows. Compared to the initial model in Figure 1, Identify and Interpret Learning Goals is added including arrows signifying the importance for teachers to align their interpretation of student responses and adapt their teaching according to the learning goals

To promote learning, the assessment process needs to be recognized as an iterative one, meaning moving back and forth between the model's building blocks guided by student responses. This involves knowing what the students should learn (learning goals), where the students are in their learning process (eliciting and interpreting students' thinking), and how to help the students toward the learning goals (action taken based on the elicited and interpreted information).

In an iterative assessment process, student responses inform both teaching and learning. Through student responses, teachers receive information on their teaching and make decisions on how to adapt the teaching to meet students' need. Students, on the other hand, receive elaborative feedback on their thinking to improve their learning. An explicit understanding of the learning goals and how to teach them are required for teachers to act upon student responses in ways that promote student understanding. Therefore, we suggest that an effective formative assessment process rests upon teachers' identification and interpretation of the learning goals. This will also help prevent formative assessment from becoming a pedagogical activity without disciplinary content.

Limitations

A limitation of this study relates to the small sample. Thus, the findings are illustrative and not intended to be representative or generalizable. The results, nevertheless, highlight insights that could add to the knowledge base of the conduct of formative assessment and how to teach for conceptual understanding.

Concluding Comments

Initially, the main focus of our study was to examine how teachers' sensitivity to student responses was related to teaching and learning scientific concepts. Then, we gradually realized the importance of teachers' interpretation of learning goals and how this impacts their sensitivity to student responses. When looking at how the teachers acted upon student responses, there were no changes in the teachers' action from pre- to post-intervention. This means that the teachers hardly used their increased access to student thinking to promote learning, either through feedback or by revising instructional decisions. According to the literature, formative assessment takes place only when assessment information is acted upon to enhance student learning (Bell & Cowie, 2001; Sadler, 1989). Thus, the participating teachers did not perform formative assessment as such. Further research is needed, especially to provide practice-oriented examples that can support teachers with low-level content knowledge how to enact formative assessment in ways that fosters conceptual understanding in students.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes

1. http://www.scienceandliteracy.org.
2. http://www.udir.no/Stottemeny/English/Curriculum-in-English/.
3. *Gravity and Magnetism,* Teacher's Guide, session 1.4, p. 81. Seeds of Science/Roots of Reading.
4. Ibid.
5. The Norwegian Directorate for Education and Training. https://gsi.udir.no/tallene/#.

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