FRAMEWORKS FOR TASK DESIGN AND TECHNOLOGY INTEGRATION IN THE MATHEMATICS CLASSROOM

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Abstract

In recent years many teachers and students have begun having good access to digital technology in their classrooms, and in the context of Sweden the majority of secondary schools are known as one-to-one schools, with students having their own computer or tablet. However, the mere presence of technology in the classroom is not a guarantee for improved teaching and learning. In fact, there is a challenge involved with integrating technology in the classroom and many teachers need support. Therefore, the aim of this thesis is to contribute to the knowledge about support for teachers integrating digital technology, especially a classroom response system (CRS), in the mathematics classroom. This is done by focusing on frameworks for CRS task design and technology integration. The thesis consists of two papers and a kappa. Both papers use data from a design research project including interventions in two cases. Paper I focuses on the development of design principles and task types for CRS tasks in a multiple-choice format aiming to engineer mathematical classroom discussions. The study generated three design principles, six task types, and 31 empirically evaluated tasks. The empirical evaluation shows that teachers consider the evaluated CRS tasks useful for engineering mathematical classroom discussions. Paper II focuses on exploring the potential of Ruthven’s (2009) SFCP framework as tool for analyzing empirical data in order to conceptualize and analyze teachers’ reasoning about critical aspects of technology integration in the mathematics classroom. The results show that the SFCP framework can be useful for capturing teachers’ reasoning about critical aspects of technology integration, but also that the framework does not capture teachers’ reasoning about students’ attitudes and behaviors. Therefore, the framework would benefit from taking into consideration students’ attitudes and behaviors, as these features are a challenge teachers need to deal with when integrating technology in the classroom. This thesis kappa, building on earlier research as well as the results and methods of its own papers, ends with an elaborated discussion on the challenges and support for teachers wanting to integrate CRS in their mathematics classroom.
To Linda, Emilia, Wilma & Ally
List of papers

This thesis is based on the following papers, referred to in the text by their Roman numerals.


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Recent decades have seen a tremendous increase in digital technology investments in education, and many teachers and students today have constant access to digital devices like smartphones, iPads and computers in their schools and classrooms (OECD, 2015). For example, in secondary school in Sweden virtually every classroom is equipped with a projector, and sometimes also an interactive whiteboard (Swedish National Agency for Education, 2016). Further, over 50% of the secondary schools in Sweden are one-to-one schools, where every student has their own computer or iPad (Swedish National Agency for Education, 2016). The arguments for these investments are likely to be related to the hope that the technology will support the teaching and enhance students’ learning. However, the integration of technology into the mathematics classroom is not a guarantee for success. It is well known that it is a challenge for teachers to use digital technology to improve learning in mathematics (Drijvers, 2013; Drijvers, Ball, Barzel, Heid, Cao, & Maschietto, 2016; Lee, Feldman, & Beatty, 2012). A pattern that emerged in the data from the PISA 2012 report (OECD, 2015) shows that investments in digital technology use have no impact, or a negative one, on students’ results. The report also points out that increased time spent on the computer in mathematics decreases students’ results, and this is especially obvious in the case of Sweden. On the other hand, there is a general consensus among researchers that the wise use of digital technologies has the potential to improve teaching and learning in mathematics (e.g., Condie & Munro, 2007; Drijvers et al., 2016; Joubert, 2013). There are also results from recent review studies (Cheung & Slavin, 2013; Li & Ma, 2010; Slavin & Lake, 2009) focusing on quantitative studies in mathematics education that show that technology integration generally has a positive effect on student learning. These differences in results might be explained by studying how the technology is used in the classroom (Drijvers, 2013, Hattie & Yates, 2014). Based on a deeper analysis of the data from “visible learning”, Hattie and Yates (2014) claim that positive effects on learning when integrating digital technology can be achieved when the intervention follows the same principles that apply to all forms of learning. They argue that, as it is the same brain that has to make an effort to learn, to improve learning the integration of digital technology should follow the principles that apply to all

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1 Average effect size 0.16–0.28.
learning forms (Hattie & Yates, 2014). This finding is similar to Drijvers’ (2013) conclusion regarding why and when technology works in mathematics education. He states that “the main guidelines and design heuristics should come from pedagogical and didactical considerations rather than being guided by the technology’s limitations or properties” (Drijvers, 2013, p. 12). Still, the schools have the technology and are expected to use it wisely to increase learning, and there is research that suggests that digital technology has the potential to improve teaching and learning in mathematics. Now, it is no longer a question whether or not mathematics teachers should use digital technology. The question is rather how to successfully integrate the digital tools and resources in the mathematics classroom (Cheung & Slavin, 2013). Therefore, there is a need for more knowledge about technology integration as well as research on interventions building on pedagogical or didactical considerations supported by technology in different contexts.

There are many different pedagogical and didactical approaches, including formative assessment (e.g., Wiliam, 2007), problem-solving (Cobb & Jackson, 2011; Samuelsson, 2010), and mathematical classroom discussions (e.g., Franke, Kazemi, & Battey 2007; Schoenfeld, 2014), that have the potential to influence student learning in mathematics. I chose to build the interventions in this study on mathematical classroom discussions\(^2\), because in Sweden the teaching of procedural skills dominates the classroom practice (Bergqvist, Bergqvist, Boesen, Helenius, Lithner, Palm, & Palmberg, 2009) and there is therefore a need for different types of practices that could give students opportunities to develop other mathematical competencies like conceptual understanding as well as reasoning and communication skills.

To establish these mathematical discussions in the classroom, teachers could use different methods, like problem-solving activities, but I chose to study the use of a digital classroom response system (CRS)\(^3\). There are several reasons for this. First of all, research suggests that CRS has the potential to support teachers and increase learning, especially in normal-sized classrooms (e.g., Caldwell 2007; Kay & LeSage 2009). Further, a teacher utilizing a CRS can launch a task, collect responses from all students, and use the results as a starting point to engineer a mathematical classroom discussion (Caldwell, 2007; Hunsu, Adesope, & Bayly, 2016; Kay & LeSage 2009; Kay, LeSage, & Knaack 2010; King & Robinson, 2009a; Krumsvik & Ludvigsen, 2012). Compared to non-digital methods like ABCD cards or mini-whiteboards\(^4\), a CRS can, for example: 1) collect a response from every student anonymously to the other students but known to the teacher; 2) automatically compile and display the responses on a chart that can be used to engineer discussions through the Peer Instruction method (cf. Crouch &

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\(^2\) See further Sections 2.3.2 for elaborations on mathematical classroom discussions.

\(^3\) See further Section 2.1 for a fuller description of CRS.

\(^4\) A description of non-digital methods compared with digital CRS is presented in Section 4.4.
Mazur, 2001) and if the teachers want to display the results to the class on a shared screen; and 3) the data can be saved and analyzed by the teacher after the lesson on a class, individual or task level in order to better plan the ongoing teaching.

However, research (e.g., Drijvers, 2013; Lee et al., 2012) has shown that there is a challenge in successfully integrating technology in a mathematics classroom, even if the implementation of technology has a good pedagogical purpose. The role of the teacher and the design of tasks are crucial factors\(^5\) for success (Drijvers, 2013; Ruthven, 2013), and to be able to design tasks and conduct lessons supported by technology, many teachers need support (Drijvers, 2013). Professional development (Borko, 2004; Desimone, 2009; Lindvall, 2016) and curriculum materials\(^6\) (Remillard, 2005; Stein & Kauffman, 2010) are two common ways to support teachers’ development of their own practices. Further, there is a lack of research and frameworks for the development of curriculum materials for CRS (Beatty, Gerace, Leonard, & Dufresne, 2006a), especially for primary and lower secondary school (cf. Hunsu et al., 2016; Kay & LeSage, 2009). Thus, there is a need for more research on support for teachers utilizing a CRS, especially in the construction of tasks.

1.1 Aim of the thesis

The overall aim of this thesis is to contribute to the knowledge about support for teachers integrating digital technology, especially classroom response system, in the mathematics classroom. This is realized by focusing on frameworks for both task design\(^7\) (Paper I) and technology integration (Paper II). Building on a content analysis in Paper II, earlier research and the results of the papers in this thesis, the intention of the kappa\(^8\) is to elaborate on and discuss critical aspects including the challenges facing, and support for, teachers wanting to integrate classroom response system in their mathematics classroom.

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\(^5\) For a more detailed description of how these factors support successful technology integration, see Section 2.3.1.

\(^6\) Including suitable tasks and teacher guides.

\(^7\) For tasks in multiple-choice format that can be used with a classroom response system.

\(^8\) In the absence of an English term for the introductory chapter of a compilation thesis, I use the Swedish kappa.
1.2 The relationship between the papers

This thesis is built on the work and data from two cases in a design research project that can be seen as a combined research and development project.

Figure 1 gives a broad overview of the research project, and shows that both papers use data from the two macro-cycles with one case each. The main focus in the research project was to develop design principles to be used with CRS in order to engineer mathematical classroom discussions, the process and results of which are presented in Paper I. In Cycle 1 I worked with one teacher, and in Cycle 2 I collaborated with six participating teachers who worked at the same school. All teachers in both cycles taught students in lower secondary school in Sweden. In addition to describing the process and results of the development of the design principles, Paper I also describes the process and results of the development of different task types and tasks, associated with the design principles. Teachers’ perceptions from Cycles 1 and 2 were used to evaluate the tasks in practice.

When analyzing the data in Paper I, I found indications that there are several aspects that might influence successful technology integration in the mathematics classroom. The teachers talked a great deal about different challenges during the interviews. These challenges provided a useful case for exploring the potential of Ruthven’s (2009) framework, the Structuring Features of Classroom Practice (SFCP). This is a relatively newly developed framework, designed to make crucial aspects of technology integration visible and analyzable. In Paper II, I then used teacher interview data from Cycles 1 and 2 and investigated the potential of Ruthven’s (2009) SFCP framework as tool for analyzing empirical data in order to conceptualize and analyze teachers’ reasoning about technology integration in the mathematics classroom.

The two papers together contribute to the knowledge about support researchers and teachers could use when designing CRS tasks and implementing CRS technology in the mathematics classroom.
1.3 Structure of the thesis

This thesis consists of a kappa with six chapters and two associated papers. This first chapter introduced the thesis and presented the relationship between the papers, as well as the aim and structure of the thesis.

To help the reader better understand the work behind the thesis, the whole development project is described in Chapter 2. This includes starting points and a description of the work conducted in the two macro-cycles.

Chapter 3 consists of a review of literature on CRS and frameworks that can be used for analyzing teachers’ technology integration in mathematics. The part related to CRS contains descriptions of important literature on CRS including classroom discussions, challenges teachers face when implementing CRS in their classroom and, finally, designing CRS tasks.

Chapter 4 discusses the methodology, describing the methods used and the arguments for the methodological choices made in the research project.

In Chapter 5 summaries of the two papers are provided.

Finally, Chapter 6 consists of conclusions based on the results of the two papers as well as discussions on the challenges faced by, and support for, teachers integrating CRS in the mathematics classroom. Further, the contributions of this thesis related to research, practice and practitioners are presented. This chapter ends with suggestions for further research.
2 Development project

As explained earlier, the whole project can be seen partly as a school development project and partly as a research project. To give the reader a better understanding of the research in my thesis, I will describe the whole development project in this chapter. The development project is based on many ideas, and consists of different actions in order to develop the teaching and the intervention, but in the research project I have chosen to focus on frameworks for task design and technology integration.

This chapter starts with a description of how a CRS is built and works in practice, and continues with a short presentation of the interventions in the development project. Further, a presentation of and elaboration on the starting points are given. Finally, the work in the two cycles is described.

Note that some parts of this chapter are also described in the methodology section, which focuses on descriptions of the methods and the arguments for the methodological choices in the research project. There are two main reasons for this: 1) the research project uses data from the development project; and 2) the reader must be able to read and understand this section without having read the methodology section.

2.1 Description of a classroom response system

To allow the reader to get a concrete idea of the digital CRS activity in this development project and therefore better understand the research project, I will describe this activity in detail.

In the project we chose to work with a web-based CRS. Figure 2, which follows, shows the main parts of such a system. It consists of a teacher device, the Internet network, student devices, and specific CRS software on the devices. For their device, the teacher and students can choose a computer, a tablet or a smartphone. These may be advantageously supplemented with a projector to let the teacher display charts showing the students’ responses.
In the preparation phase before a lesson, the teacher can construct tasks and prepare a sequence of tasks in a software program. It is also possible to supplement the tasks with a picture. The tasks can be written in different formats, such as multiple-choice, true-false or short answer. During the lesson the teacher invites the students into a personal “room” in the software program. The students fill in the room name and, if the teacher requests it, their names as well. The teacher can then choose to launch the tasks in student-paced or teacher-paced mode. In the development project we tested both variants, but the research focused on tasks to be used in teacher-paced mode. In the student-paced mode, the students work at their own pace with one or several tasks. The teacher can choose to let the program automatically deliver instant feedback after every submitted answer. The feedback can provide information about the correctness of a student’s answer, supply the correct answer, and/or give a written explanation of or hint to the solution. Every student answer can be monitored in real time and compiled on a chart on the class, task or student level in the teacher’s software program. In the teacher-paced mode, the students can only submit an answer to the specific task the teacher has launched. After submitting the answer, the students need to wait for the teacher to launch the next task or, as in this project, wait for a discussion before the next task is launched. In this project the teacher often performed a quick analysis of the results and then decided whether to continue with a peer or class discussion. Before or after conducting these discussions, the teacher could choose to display the chart for the students on a
shared screen using the projector. To recap, the CRS helps the teacher launch, collect, monitor, and finally compile students’ answers on a chart.

2.2 The interventions in Cycle 1 and Cycle 2

As illustrated earlier, Figure 3 shows that the work in this project was conducted during two macro-cycles consisting of one case each.

Figure 3. The project and the two macro-cycles (Gustafsson & Ryve, 2016, p. 88).

In Cycle 1 the development project focused on promoting the wise use of ICT and establishing a formative assessment practice supported by CRS. The intervention consisted of three different teaching strategies (e.g., Wiliam, 2007): 1) engineering mathematical classroom discussions; 2) evaluating teaching and learning; and 3) conducting self-assessment, in order to promote a formative assessment practice. These strategies were implemented in the classroom, with specific tasks and questions launched with the CRS.

In Cycle 2, the project focused on increasing the interactivity in the classroom and giving the students better opportunities to develop different mathematical competencies according to the syllabus. This was done by establishing a flipped classroom method (cf. Bishop & Verleger, 2013) to gain time for conducting mathematical classroom discussions supported by specific tasks and CRS.

To recap, the two cycles had different development goals, but in both cycles the teachers used tasks supported by CRS to establish mathematical classroom discussions in order to accomplish their goals. In these discussions, CRS can be seen as a means to improve the efficiency and strengthen

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9 For examples of implemented tasks, see Paper I.
10 In this thesis, in the context of teaching and learning, I use the term interactivity to refer to a meaningful interaction between teachers, students and the mathematical content (Roschelle, 2009).
11 Conceptual understanding and procedural, reasoning, communication and problem-solving competencies.
12 Including video-recorded lessons to be watched at home and interactive lessons in the classroom.
the effect of these tasks and questions, and also as a means to reorganize the classroom practice by forcing every student to be active and contribute their knowledge.

2.3 Starting points

The interventions are built on and guided by several ideas derived from theory and literature. The main reason for building the interventions on several ideas is that teaching is complex, and many factors influence students’ learning. The main aim of the development project was to develop the teaching and the intervention, not to isolate and compare whether Method A is better than Method B (Reeves, 2006). Table 1 summarizes the ideas and how they were operationalized in the two cycles. Thereafter follow sections offering more descriptions of every idea and how it is operationalized in the project.

Table 1. Starting points of the development project. C1 = Cycle 1 and C2 = Cycle 2. + means that it was present and - means that it was absent during the work.

<table>
<thead>
<tr>
<th>Idea</th>
<th>Operationalization</th>
<th>C1</th>
<th>C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology integration should build on a pedagogical or didactical idea, if it is to improve teaching and learning (Drijvers, 2013; Hattie &amp; Yates, 2014).</td>
<td>Utilizing a CRS and specific tasks to engineer mathematical classroom discussions to support formative assessment strategies and increase the interactivity.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Students’ thinking can be improved through dialog in classroom discussions (Fraivillig, Murphy, &amp; Fuson, 1999).</td>
<td>Utilizing a CRS to collect and elicit students’ thinking and thereafter improving their mathematical thinking through instructional strategies in a whole-class discussion. Using the Peer Instruction method to exploit student interaction and focus students’ attention on important mathematical concepts and procedures.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Interactivity can improve teaching and learning (Hake, 1998; Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, &amp; Wenderoth, 2014).</td>
<td>Conducting peer and whole-class discussions and forcing every student to be active by utilizing a CRS to launch specific tasks, collect all student answers, display the results on a shared screen, and then orchestrate discussions. Using the flipped classroom method to gain more time for interactivity during the lessons.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Formative assessment can improve teaching and learning (e.g., Black &amp; Wiliam, 1998; Hattie, 2009).</td>
<td>Implementing a formative assessment practice supported by CRS and specific tasks.</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
2.3.1 Technology integration

Drijvers (2013) analyzed six successful cases of technology integration in mathematics education, and identified three important factors that promote or hinder successful integration: 1) the design; 2) the role of the teacher; and 3) the educational context. The factor of design concerns the design of the technology, the design of associated tasks and activities, and finally the design of the lessons and teaching. In this project the design of the digital software was important, and I conducted an analysis of affordance and constraints before choosing an appropriate software program. The design of the tasks was a prioritized focus in the whole project and a central part of the research focus. Concerning the design of the lessons and the teaching, we took our departure from research suggesting that the design of an intervention with technology integration should build on a pedagogical or didactical idea if it is to improve teaching and learning (Drijvers, 2013; Hattie & Yates, 2014). In the project we utilized a CRS and used corresponding specific tasks to support formative assessment strategies, increase interactivity, and establish and engineer mathematical classroom discussions.13

The second factor for successful integration concerns the role of the teacher, who has to orchestrate for learning (Drijvers, 2013). In order for the teacher to do this, Drijvers (2013) point out the importance of professional development. The teacher has to develop his or her technological and pedagogical content knowledge (cf. Mishra & Koehler, 2006). In the project we used technology and software that were easy to learn and use, and the teachers were given a lecture on why and how to use it in a wise way in practice. In the second cycle we also followed up the lecture with a workshop where the teachers could try out the technology and ask questions. We also exchanged our experiences in group discussions after every trial in practice.

Drijvers’ (2013) third factor concerns the educational context. Drijvers points out the importance that the technology be integrated into the educational context in a natural way. In the project, the technology was used in different ways to support or establish different elements of the educational contexts. For example: a) focusing more on conceptual knowledge; b) conducting peer and whole-class discussions in which students were encouraged to share their knowledge and learning; and c) using students’ answers to tasks as a source for mathematical classroom discussions. These elements in the educational context were not completely new to the teachers or their students, but in the intervention they became a natural part of the mathematics lessons.

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13 These strategies are described in Sections 2.3.2-2.3.4.
2.3.2 Mathematical classroom discussions

There are several theories, like social constructivism (Ernest, 2010) and socio-cultural theory (Säljö, 2014), which stresses the importance of communication between people in learning. According to Vygotskij (1978) and Säljö (2014), learning is an activity that first takes place through communication between people in a social activity, after which the individual reflects on the social activity and makes sense of it and internalizes it on an internal plane. Based on this theoretical perspective, teachers need to conduct discussions. This idea is supported by empirical research (Hiebert & Grows, 2007; Franke et al., 2007; Schoenfeld, 2014) that suggests that mathematical classroom discussions are an important element in productive mathematics teaching, and in this project as well, and there are many reasons to engage students in discussions. Wiliam and Thompson (2007) stress the importance of engineering classroom discussions in a formative assessment practice to get information on how students think, in order to make better judgments about the next step in teaching. Further, according to Franke et al. (2007), researchers can see communication in many different ways, for example: a) as a possibility to create a mutual, shared knowledge that could serve as a resource; b) as an opportunity for multiple ways to participate with the content; c) a way to develop the mathematical practices; and d) as an opportunity to develop mathematical knowledge. Even though research stresses the importance of conducting productive discussions in the classroom, this seems to be a challenge for teachers (Franke et al., 2007; Larsson, 2015). Fraivillig et al. (1999) showed that during mathematical classroom discussions many teachers support students’ thinking, but that it is less common that teachers elicit students’ explanations of solution methods or extend their mathematical thinking. Furthermore, according to Franke et al. (2007), the IRE pattern – with teacher-initiated question/student response and teacher evaluation – is common in mathematics classrooms. This pattern does not offer good opportunities to advance students’ thinking (Fraivillig et al., 1999). Therefore, the teacher has a prominent role in moving away from the unproductive IRE pattern in the classroom and supporting productive mathematical discussions (Franke et al., 2007). As stressed above, this is not easy. Teachers need to use suitable, good tasks and have a repertoire of instructional strategies (e.g., Franke et al., 2007; Larsson, 2015; Wiliam, 2007).

Participation in these mathematical classroom discussions should not be an option, and there are instructional strategies that teachers can use to engage all students (Wiliam, 2007). The “no hands up” instructional strategy could be useful in engaging all students mentally; this means that the teacher chooses who has the opportunity to answer the question, and the students are not allowed to raise their hands unless they want to pose a question of their own. Further, the framework by Fraivillig et al. (1999) for Advancing Children’s Thinking in mathematics (ACT framework) points out three important
instructional components for developing students’ conceptual understandings in classroom discussions: 1) eliciting their solution methods, 2) supporting their conceptual understandings, and 3) extending their mathematical thinking. Eliciting students’ solution methods includes strategies for: a) facilitating their responding, including techniques such as eliciting multiple solution methods for one task or encouraging students to elaborate on their responses; and b) orchestrating productive classroom discussions, including techniques such as using students’ explanations as lesson content and deciding which methods to discuss or which students who should have the opportunity to speak (Fraivillig et al., 1999). Supporting students’ conceptual understandings includes strategies for supporting the thinking of both describers and listeners, including techniques such as reminding students of similar problem situations, assisting them in clarifying their own methods, or asking them to explain a peer’s solution (Fraivillig et al., 1999). Extending students’ mathematical thinking includes knowledge about the following strategies: a) maintaining high expectations for all students, including techniques for encouraging everyone to attempt so solve difficult tasks and try various methods; b) encouraging mathematical reflection, including techniques such as asking students to analyze, compare and generalize concepts as well as showing and asking them to reflect on different solution methods; and c) going beyond initial solution methods, including techniques such as pressing students to try other solution methods and encouraging them to use more efficient methods. The three components in the ACT framework are not completely separate, and there are techniques that can support more than one component. For example, Wiliam (2007) stresses the importance of giving students enough time to think and respond, and of teachers listening more interpretatively to their answers instead of listening evaluatively. According to Fraivillig et al. (1999), this technique both elicits and supports students’ thinking. Further, highlighting and discussing errors and using challenging follow-up questions may both elicit and extend students’ thinking (Fraivillig et al., 1999).

In the project, I regard a good mathematical classroom discussion as one that seeks to include Schoenfeld’s (2014) five features for a powerful mathematics classroom. Schoenfeld (2014) has developed a framework, Teaching for Robust Understanding of Mathematics (TRU Math), in order to define a powerful classroom and support the teacher in creating it. TRU Math includes and describes the importance of five features (Schoenfeld, 2014), which can all easily be related to mathematical classroom discussions: 1) The mathematics: the discussed mathematics is focused on connections between procedures, concepts and contexts; 2) Cognitive demand: the classroom interactions are productively and intellectually challenging to the students; 3) Access to mathematical content: the classroom activity supports the active engagement of all students with a focus on the central mathematics; 4) Agency, authority, and identity: students have opportunities to conjecture,
explain, make mathematical arguments, and build on one another’s ideas; and 5) Uses of assessment: the teacher solicits student thinking and plans the ongoing teaching accordingly by building on productive beginnings or focusing on misconceptions.

As stated above, we used CRS and associated tasks to give teachers and students opportunities to engage in mathematical classroom discussions. In order to succeed, the design of tasks is a critical aspect, as is the role of the teacher (Drijvers, 2013). Teachers played an important role in initiating and conducting these discussions, in order to develop the students’ thinking. One idea in the development project was to use CRS and the Peer Instruction method (cf. Crouch & Mazur, 2001) to use students’ responses in specific CRS tasks as a base for engineering and conducting the mathematical classroom discussions in order to elicit, support and advance their thinking (Fraivillig et al., 1999). In this way, the teacher could build the discussion on the students’ perceptions and understandings to improve their mathematical thinking. The CRS supported the teacher by gathering and compiling all student responses on a chart. This information was used as a starting point in the discussions. To be able to do this, the teachers used different instructional moves like posing suitable questions or sharing interpretations of students’ claims, repeating students’ claims, or having students repeat their peers’ claims in order to elicit, support and advance the students’ thinking (Cengiz, Cline, & Grant, 2011; Fraivillig et al., 1999). Further, the Peer Instruction method supported the teachers in Cycle 2 to decide whether or not to conduct a peer discussion before a whole-class discussion. In Cycle 2 the teachers were also supported with a teacher guide associated with the tasks, including questions that could be used to elicit, support and advance the students’ thinking during the discussions.

2.3.3 Interactivity

There are empirical evidence that increased interactivity can improve learning (e.g., Freeman et al., 2014; Hake, 1998). In a study building on data from conceptual and problem-solving tests with six thousand students in physics courses, Hake (1998) defines interactivity methods as “methods as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors” (p. 65). Additionally, he defines traditional lectures as passive-student lectures with little or no use of interactivity methods (Hake, 1998). The study (Hake, 1998) shows that classroom use of interactivity methods can enhance student learning much more than the traditional lecture. These findings can be supported by other studies (Freeman et al., 2014;

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14 See further Section 3.1.2 for a fuller description of Peer Instruction.
Ruiz-Primo, Briggs, Iverson, Talbot, & Shepard, 2011; Springer, Stanne, & Donovan, 1999). For instance, in a meta-analysis of 383 reports, Springer, Stanne and Donovan (1999) found that various forms of small-group learning in science, mathematics, engineering, and technology courses could enhance student learning. In a more recent meta-study, Freeman et al. (2014) show that active learning methods that “included approaches as diverse as occasional group problem-solving, worksheets or tutorials completed during use of personal response systems with or without Peer Instruction, and studio or workshop course designs” (p. 8410) could increase student learning and improve the average exam score by 6%. They also found that during traditional lecturing, in which students are passive, students were 1.5 times more likely to fail compared to those in classes using active learning.

In this project we increased the interactivity by utilizing a CRS to launch specific tasks, collect all students’ responses, and display the results on a shared screen and use them as a foundation for peer as well as whole-class discussions. In this way, the students were forced to explore, think about, and argue about mathematical concepts or ideas.

2.3.3.1 Flipped classroom
The flipped classroom method uses both video lectures and sometimes control questions as homework, in order to gain more classroom time for interactive activities such as group-based problem-solving. In a survey of the research on flipped classroom, Bishop and Verleger (2013) concluded that students’ perceptions of it are generally positive. Few studies objectively investigating student learning outcome were found, but there is evidence suggesting that flipped classroom can improve student learning (Bishop & Verleger, 2013).

In this project, the teachers in Cycle 2 decided to try the flipped classroom method. We used video lectures on important concepts and procedures for students to watch at home before the lessons. In the classroom the teacher increased the interactivity by spending more time on discussion tasks, launched and conducted using a CRS.

2.3.4 Formative assessment
The main idea of formative assessment is that teachers should regularly gather evidence of student learning, in order to adjust and better plan the ongoing and upcoming teaching (Hattie, 2009; Wiliam, 2007). Literature reviews (Black & Wiliam, 1998; National Mathematics Advisory Panel, 2008; Swedish Research Council, 2015) and a meta-analysis (Hattie, 2009) have shown that formative assessment has great potential to enhance student learning. A Swedish literature review by the Swedish Research Council (2015) and a report by the US Department of Education (National Mathematics Advisory Panel, 2008) suggest that the positive effects also apply in
the context of mathematics. The Swedish Research Council (2015) analyzed five international studies, all of which showed a positive effect on learning in mathematics. Studies in mathematics in the Swedish context reinforce these results (Andersson, 2015; Balan, 2012).

Literature reviews (Caldwell, 2007; Kay & LeSage, 2009) and case studies (Beatty & Gerace, 2009; Draper & Brown, 2004; Jones, Antonenko, & Greenwood, 2012; Kay et al., 2010; King & Robinson, 2009a; Krumsvik & Ludvigsen, 2012) on CRS use highlight that one of the most important benefits of using a CRS is the potential to improve formative assessments. They especially point out the possibility and effectiveness of regularly gathering evidence of students’ learning with the CRS, in order to regulate the learning process.

In order to help teachers establish a formative assessment practice in the classroom, Wiliam and Thompson (2007) developed a conceptual framework that identifies key persons and processes of formative assessment. From a combination of this framework and the “big idea” of formative assessment that stresses the importance that teachers regularly gather evidence of student learning in order to adjust the teaching to better meet the students’ needs, Wiliam and Thompson (2007) illuminated five key strategies for formative assessment:

1. clarifying and sharing learning intentions and criteria for success;
2. engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding;
3. providing feedback that moves learners forward;
4. activating students as instructional resources for one another; and
5. activating students as the owners of their own learning.

These strategies were an important foundation in planning the development project in Cycle 1 and the different ways to use the CRS in the classroom. However, the use of CRS to engineer and conduct classroom discussions (Beatty et al., 2006a; Wiliam, 2007) and peer learning (Beatty & Gerace, 2009; Caldwell, 2007; Cline, Zullo, Duncan, Stewart, & Snipes, 2013; Crouch & Mazur, 2001; Deslauriers, Schelew, & Wieman, 2011; Draper & Brown, 2004; Kay & LeSage, 2009) in both Cycles 1 and 2 harmonizes with a formative assessment practice because it: 1) engages and activates students in discussions of and reasoning about important concepts or ideas as they can learn through feedback and reflection; and 2) allows teachers to gather evidence of students’ thinking and learning (Wiliam, 2007) in order to better plan the continued teaching.

2.3.4.1 Feedback
Feedback is a key component in a formative assessment practice (e.g., Wiliam, 2007), and Shute (2008) defines it as “information communicated to the learner that is intended to modify his or her thinking or behavior for the purpose of improving learning” (p. 154). In a review of literature on feedback
Hattie and Timperley (2007) point out the importance of timing in feedback, and a US study (Brosvic, Dihoff, Epstein, & Cook, 2006) has shown that students performing mental calculation tasks benefited from instant feedback compared to delayed or no feedback. The study showed no differences between computer-assisted feedback and personal feedback from the teacher. In a more recent meta-analysis on the effects of item-based computer-assisted feedback on students’ learning, Van der Kleij, Feskens and Eggen (2015) found that feedback providing an explanation produced larger effect sizes (0.49) than feedback providing only the correctness\(^{15}\) (0.05) or the correct answer (0.32).

In this project the CRS was used to improve the feedback process (Grez, 2010; Jones, Antonenko, & Greenwood, 2012; Kay & LeSage, 2009; Tollboom, 2012) by keeping each student anonymous to the other students but known to the teacher, and effectively collecting and summarizing the responses on a chart on a single or shared screen. In this way, the CRS delivered frequent and instant feedback to students in direct relation to the tasks and also provided information to the teacher on the students’ knowledge. This information served as a basis for well-founded decisions for the ongoing teaching and the possibility to use delayed feedback. Feedback was also an important element when the teachers took advantage of students’ responses from the CRS tasks and used them to engineer and orchestrate classroom discussions, in which instant feedback often went beyond the correct response to the task and led to a discussion of why different answers are correct or incorrect.

In Cycle 1, in addition to discussion tasks we also used CRS and associated tasks to assess students’ knowledge before, during and after teaching, and we also provided questions to allow students to assess their own level of understanding. In mental calculation tasks we used the CRS software to provide automatically generated instant feedback, providing: 1) the correctness, 2) the correct answer, and/or 3) an explanation.

2.4 Cycle 1

As mentioned above, the development project in Cycle 1 focused on promoting the wise use of ICT and implementing a formative assessment practice supported by CRS. The work was guided by and divided into four phases (cf. McKenney & Reeves, 2012; Reeves, 2006) – 1) analysis and exploration, 2) development, 3) implementation, and 4) evaluation – which taken together complete a macro-cycle. These phases are used to structure the sections on the work in these two cycles.

\(^{15}\) Right or wrong.
2.4.1 Analysis and exploration

The analysis started with an orientation of the problem area through a literature study. The intention with this literature study was to reveal and understand how others had addressed and used CRS to support formative assessment, and with what results (McKenney & Reeves, 2012). I explored earlier research on formative assessment, CRS, formative assessment supported by CRS, and task design. Then, I discussed the project with colleagues and teachers. Further, the participating teacher was recruited at a secondary school with students in Grades 6 to 9. The school was known as a one-to-one school, with all students having access to their own laptop PC. In collaboration with the teacher, I investigated some critical aspects (Ruthven, 2009) and practical issues of technology integration, for example classroom design, lesson length, networks, computers and the computer skills of the teacher and students. Then, the teacher received a short introduction to CRS and the chosen software. We also discussed testing different types of CRS tasks for different formative assessment purposes. We decided to develop and test two types of tasks mainly related to Wiliam and Thompsons (2007) key strategy 2 for formative assessment\(^\text{16}\) that stresses the use of tasks and questions that could reveal students’ understanding and thinking. Firstly, CRS tasks in multiple-choice format, aiming at engineering mathematical discussions at the beginning of the lessons. Secondly, we also decided to test CRS tasks in both short-answer and multiple-choice format, for the main purpose of mapping the students’ knowledge before and after teaching as well as evaluating the teaching at the end of the lessons. Furthermore, we also decided to test self-assessment questions in relation to evaluation tasks.

We chose to work with CRS software called Socrative\(^\text{17}\) for this project. Arguments for this choice are described in the methodology section. Further, we decided to implement the CRS tasks for eight weeks, while they worked with the content of fractions and percentages.

2.4.2 Development, implementation and evaluation

In the development phase, a first draft of design principles\(^\text{18}\) for the three types of formative assessment strategies was developed: 1) engineering mathematical classroom discussions\(^\text{19}\); 2) evaluating the teaching and getting information about the students’ knowledge; and 3) self-assessment. The principles were derived from literature on formative assessment, CRS tasks and multiple-choice tasks. Thereafter, I constructed tasks based on these

\(^{16}\) The use of the tasks also relates to Wiliam and Thompsons (2007) strategy 3, 4 and 5.

\(^{17}\) www.socrative.com

\(^{18}\) For a more detailed description and explanation of design principles, see Section 4.5.1.

\(^{19}\) The development of design principles for engineering mathematical classroom discussions is a central focus of the research in Paper I.
principles and the teacher’s lesson goals. Task format and wording were then evaluated with a checklist created based on Haladyna, Downing and Rodriguez’s (2002) literature review of research on how to formulate good multiple-choice tasks.

We implemented and evaluated a total of eight CRS tasks constructed to engineer mathematical classroom discussions. Further, the teacher performed a pre-test with 18 tasks constructed to get information on the students’ knowledge, supplemented with 18 questions focusing on self-assessment. Additionally, 45 tasks focusing on evaluating the teaching and getting information about the students’ knowledge, as well as 19 questions regarding self-assessment, were used during these eight weeks at the end of the lessons.

After the implementation phase, I conducted a summative evaluation of the interventions based on the collected data. The knowledge and experience gained in Cycle 1 were then used to plan the next cycle, adjust the design principles, and develop new tasks.

2.5 Cycle 2

As mentioned above, the project in Cycle 2 aimed at increasing the interactivity in the classroom and giving the students better opportunities to develop different mathematical competencies according to the syllabus.

2.5.1 Analysis and exploration

Six participating teachers were recruited at a one-to-one secondary school with students in Grades 6 to 9. We chose to implement a flipped classroom method including video lectures for students to watch at home in order to gain more time for mathematical classroom discussions during the lessons, supported by CRS and specific tasks.

A complementary exploration of literature, mainly on flipped classroom, CRS and CRS tasks in multiple-choice format were carried out. The intention with this additional literature study was to gain knowledge about flipped classroom and deepen my understanding about how others had addressed CRS tasks aiming to engineer classroom discussions, and with what results (McKenney & Reeves, 2012).

To give the teachers an idea of why, how and when a CRS can be used in practice, I gave a two-hour lecture on this. This was followed by a two-hour workshop, where the teachers tested the chosen CRS software and discussed the forthcoming lessons. Additionally, we investigated some critical aspects

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20 Especially conceptual understanding as well as reasoning and communication competence.
21 Every student had his or her own laptop.
(Ruthven, 2009) and practical issues of technology integration, for example classroom design, lesson length, networks, computers, and the computer skills of the teachers and students. Once again the topic of fractions was selected, and we planned to use CRS tasks in three lessons for a period of three months. The participating teachers’ perceptions of the learning progression of fractions guided the choice of content for the three lessons.

2.5.2 Development, implementation and evaluation

The teachers did not develop the flipped movie lectures. In order to save time, they selected other teachers’ movie lectures on the Internet, to be watched by the students at home before every lesson.

The design principles for constructing starter tasks were revised and modified in relation to experience from Cycle 1 and the additional study of relevant literature. They were also accompanied by descriptions of generic task types\(^{22}\) that fulfilled these principles. Further, tasks with respect to the different task types, the design principles, and the learning goals of the specific lessons were developed. Before each lesson\(^ {23} \) I met with the participating teachers, and presented and discussed the tasks and their aims. The teachers, working in pairs, selected two to eight tasks to be used in each lesson. A total of 67 tasks were constructed to be used during three different lessons on fractions, and 23 of these were selected, implemented and evaluated in the classrooms.

The tasks for Lessons 2 and 3 were supplemented with a teacher guide in order to support the teachers in implementing them. The guide contained aim and goals, solutions, teaching strategies, discussions on the distractors building on common misconceptions or mistakes, and suggestions for follow-up questions in order to advance the students’ mathematical thinking. The main reason for producing this guide was to support the teachers in implementing these CRS tasks and conducting the associated whole-class discussion.

After the implementation phase, I again conducted a summative evaluation\(^ {24} \) of the interventions based on the collected data.

2.6 Summary of the development project

The development project consisted of work in two macro-cycles, consisting of one case each, at two lower secondary schools in Sweden. The two cases had different development goals, but in both cycles the teachers used CRS tasks in order to engineer mathematical classroom discussions, which was

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22 For a more detailed description of the task type framework, see Paper I.
23 They used CRS tasks during three different lessons.
24 For more details, see Paper I and Chapter 4.
the focus of the research project. The project had several starting points, for example the importance of mathematical classroom discussions and interactivity in the classroom. The work in the two cycles, guided by and divided into four phases (e.g., McKenny & Reeves, 2012), started with a study of relevant literature and an analysis of the CRS software. In the development phase, different CRS tasks were constructed with respect to design principles. The interventions including these tasks were implemented and evaluated in practice by the participating teachers.
3 Literature review

This chapter starts with a review of CRS including different pedagogical purposes of CRS tasks and classroom discussions. Then, literature on challenges faced by and support for teachers integrating CRS in the classroom is presented including a section on designing CRS tasks. The literature on challenges is needed in order to discuss the CRS support in this thesis. The review of literature on task design is a summary; more can be found in Paper I. Finally, to be able to discuss the results and argue for the choice of framework in Paper II, a description of Ruthven’s (2009) framework for analyzing technology integration is provided.

3.1 Classroom response system

The classroom response system (CRS) is a relatively new technology that has drawn the attention of teachers and researchers in recent years, especially in higher education (Caldwell 2007; Hunsu et al., 2016; Kay & LeSage 2009). Evidence in research suggests that this digital tool has the potential to support teachers and increase learning (e.g., Caldwell 2007; Kay & LeSage 2009). Several benefits have been documented, including increased interactivity and establishing mathematical discussions as well as improved student engagement and attendance (e.g., Draper & Brown, 2004; Hunsu et al., 2016; Kay & LeSage, 2009). In a literature review of 67 peer-reviewed papers, Kay and Lesage (2009) show that there is clear evidence from qualitative research that CRS use can improve student learning. Further, Kay and Lesage (2009) point out that several experimental studies show that CRS use in lectures significantly outperforms a traditional lecture method. Studies (e.g., Caldwell, 2007; Draper & Brown, 2004) also show that students’ quality and depth of knowledge can increase when their responses are compared and discussed with peers and the class. However, there are also studies that show no or little effect on learning (e.g., Kay & LeSage, 2009). These differences in results can be supported by a recent meta-analysis of CRS effects on learning and affective factors (Hunsu et al., 2016). Hunsu et al. (2016) show that CRS in general has a small but positive effect on student learning, but there are large differences in effects depending on the context. For example, Hunsu et al. (2016) show that class size influenced the effect on learning. The strongest effect can be seen in normal-sized classes with
21-30 students. When there are more than 50 students in a class, the effect decreases dramatically. The ambiguity in learning outcomes could also be explained by how the tools have been used, as is the case with all technology use in schools (Drijvers, 2013; Hattie & Yates, 2014; OECD, 2015). For example, in a design research study, Tolboom (2012) suggests that the differences on the impact on student performance can be explained by different methods of orchestrating the teaching in a CRS classroom and differences between teachers’ beliefs and knowledge.

To recap, research suggests that CRS, if used productively, can facilitate teaching and increase student learning by establishing productive classroom practices (e.g., Caldwell, 2007; Draper & Brown, 2004; Hunsu et al., 2016, Kay & LeSage, 2009), especially in normal-sized classrooms.

3.1.1 Pedagogic purpose of CRS tasks

There are many different objectives for using tasks and questions with support from a CRS (e.g., Caldwell, 2007; Kay & LeSage, 2009). Some of the common applications I mentioned above increase interaction by engineering classroom discussions (e.g., Beatty et al., 2006a; Caldwell, 2007; Kay & LeSage, 2009) and promoting peer discussions (e.g., Caldwell, 2007; Kay & LeSage, 2009; Smith, Wood, Adams, Wieman, Knight, Guild, & Su, 2009). CRS can also be used to collect responses after a discussion or debate (Caldwell, 2007). Further, CRS tasks can also be used to assess student preparation and ensure that students take responsibility for their homework and prepare themselves for class (Knight & Wood, 2005). Another common application for CRS questions is to learn more about students’ opinions on the teaching, topic, attitudes and so on. It is also common that questions and tasks are used for purposes of formative assessment, by: a) assessing students’ pre-existing knowledge before teaching; b) assessing their understanding during and after a lecture; c) assessing their understanding of previous lessons; d) assessing their ability to apply knowledge in new situations; and finally e) allowing them to assess their own level of understanding (e.g., Beatty et al., 2006a; Caldwell, 2007; Kay & LeSage, 2009). Students’ responses in these formative tasks and questions can be used to determine future directions of teaching. More, another common use of CRS tasks is quizzes or tests, to check whether students are paying attention, have done their homework, or are able to recall previous teaching material (e.g., Caldwell, 2007). Finally, CRS tasks can also be used to review earlier teaching content at the end of lessons or before a test (Jackson & Trees, 2003).

Some researchers and teachers use the CRS tasks or questions as a core in their teaching. For instance, Beatty, Leonard, Gerace and Dufresne (2006b) developed a CRS-based teaching model called Question-Driven Instruction (QDI), which they have tested and evaluated in physics and mathematics. They assert that in this model the questions and tasks do more than simply reinforce traditional teaching; they build the core of the teaching. The prima-
ry objective is not to give a lecture on the content. They state that the goal of QDI is “…to help students explore, organize, integrate, and extend their knowledge” (Beatty et al., 2006b, p. 2). Thereafter, the researchers developed QDI into a method called Technology-Enhanced Formative Assessment (TEFA), which has a broader foundation in theory and formative assessment and includes QDI (cf. Beatty & Gerace, 2009) as a key component. Furthermore, another method, to be used with clickers, is Mazur’s Peer Instruction25 (cf. Crouch & Mazur 2001; Lasry, Mazur, & Watkins, 2008).

3.1.2 CRS and classroom discussions

Earlier research has shown that CRS has the potential to support teachers in engineering and conducting classroom discussions and peer learning, mainly aiming to develop students’ conceptual understanding (Beatty et al., 2006a; Beatty & Gerace, 2009; Caldwell, 2007; Cline et al., 2013; Crouch & Mazur, 2001; Deslauriers et al., 2011; Draper & Brown, 2004; Kay & LeSage, 2009). This could be done through teaching strategies like Peer Instruction (Crouch & Mazur, 2001) or QDI (Beatty et al., 2006b). These strategies force students to compare and discuss their understandings with their peers before and/or after answering a CRS task, and then defend their answers in a whole-class discussion. The Peer Instruction method also helps the teacher to decide whether or not to conduct a peer discussion before a whole-class discussion. Crouch and Mazur (2001) have shown that if 30-70% of students’ responses are correct, they will benefit from a peer discussion. In a more recent study, Lasry, Mazur and Watkins (2008) show that the Peer Instruction method can increase students’ conceptual learning and problem-solving ability in physics.

3.1.3 Challenges for teachers

Even if the CRS use is built on a good pedagogical or didactical idea in mathematics, teachers need to overcome a number of challenges or barriers in order to successfully implement these teaching strategies (Feldman & Capobianco, 2008; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). The research is quite limited in knowledge about the barriers and challenges involved with implementing different teaching strategies supported by CRS (Lee et al., 2012). However, some interesting results can be found in the combined research and PD development program by Lee et al. (2012). Their study was conducted in the US in middle and high school, with eleven science teachers and seven math teachers. I will now describe these findings and relate them to other research findings.

25 See further Section 3.1.2 for a fuller description of Peer Instruction.
A common challenge for teachers is related to technical problems and the utilization of both hardware and software for CRS use (Beatty, Feldman, Leonard, Gerace, Cyr, Lee, & Harris, 2008; Caldwell, 2007; Feldman & Capobianco, 2008; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). Teachers’ utilization is affected by their technical skills and knowledge about the software, malfunctions in the hardware, and limitations in the software (Kay & LeSage, 2009; Lee et al., 2012). The limitations entail the CRS software not doing what the teacher wants it to (Lee et al., 2012). These challenges are also related to teachers’ perceived lack of adequate technical support for resolving these technical problems (Beatty et al., 2008; Caldwell, 2007; King & Robinson, 2009b; Lee et al., 2012). However, results from the mixed-method study by Beatty et al. (2008) in the US with 39 teachers in middle and high school show that these technical problems decrease within a month, as the teachers become more comfortable with the CRS.

One of the major challenges for teachers is related to time and the pressure to ensure coverage of the teaching content (Beatty et al., 2008; Caldwell, 2007; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). Firstly, teachers need more preparation time in order to develop a CRS task and plan the teaching with CRS (King & Robinson, 2009b; Lee et al., 2012). Secondly, classroom discussions are time-consuming (Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). Thirdly, setting up and closing down the CRS, as well as transitions between CRS use and “ordinary” teaching, are time-consuming (Beatty et al., 2008; Caldwell, 2007; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). The fourth and final factor involves content coverage. Many studies report that teachers believe that the teaching proceeds more slowly with CRS use, and therefore less content is covered during the lessons (Beatty et al., 2008; Caldwell, 2007; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012).

Another major challenge for teachers concerns the difficulty in finding or developing effective CRS tasks for different purposes (Beatty et al., 2008; Caldwell, 2007; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). Beatty et al. (2008) state that teachers “realize that designing effective questions is more challenging than it at first appears, and spend much of the first year (or more) focused on this” (p. 21). Lee et al. (2012) report that some teachers struggled with simply getting started; they also struggled with developing tasks that a) would be interesting and motivating, b) could provide information and insight about student understandings, and c) would provoke a class discussion.

When overcoming the technical challenges and starting to master the difficulty of task design, teachers often become concerned about their role and orchestration of classroom discussions (Beatty et al., 2008). According to Lee et al. (2012), teachers’ use and orchestration of whole-class discussions
are affected by their knowledge and skills in this area. The conducting of these whole-class discussions is related to formative assessment strategies. First, teachers struggle with difficulties in understanding students’ thinking based on the CRS responses and the students’ contributions to peer and whole-class discussions (Lee et al., 2012). Second, in accordance with the CRS results and the discussions, the teachers have to 1) instantly think about, react and adjust their teaching and revise the lesson, and 2) think about how to adjust the ongoing and upcoming lessons (Kay & LeSage, 2009; Lee et al., 2012).

Other identified challenges related to teachers are contextual factors, beliefs and confidence level (Lee et al., 2012). The contextual factors refer to general aspects like personal life, school events, time of day, etc., which affect teachers’ teaching.

However, research also reports on challenges related to students and student behavior (Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). Inappropriate behavior by students tends to affect teachers’ ability to conduct class discussions. Lee et al. (2012) report that some teachers had little confidence in their students’ ability to work in small groups, and sometimes did not believe their students could participate in a lengthy whole-class discussion. They also report that teachers had noticed that students were frustrated by ambiguous CRS tasks, or tasks with no clearly correct answer. King and Robinson (2009b) report on another interesting finding: that CRS could distract students if the tasks were too easy or the handsets did not work.

To recap, there are some challenges that teachers have to encounter. Research has identified factors that are related to the technology, the teachers, and the students. The major challenges are related to the hardware and software themselves and the use of them, time and coverage of content, the design of good and effective CRS tasks, and the orchestration of discussions. Even though there are some challenges, those related to the technology itself and its use could be decreased with time of use (Beatty et al., 2008). Caldwell (2007) also points out that “generally this decreased coverage is considered more than compensated by perceived improvements in student comprehension, instructor awareness of student difficulties, and the ability to assess instantly whether the pace of the course is appropriate” (p. 14). Finally, according to Lee et al. (2012), many of these challenges could be decreased with proper support.
3.1.4 Designing CRS tasks

In this section I present a summary of research related to designing CRS tasks. For a fuller review of literature on this aspect, the reader is referred to Paper I. As pointed out in the previous section, one of the greatest challenges for teachers utilizing a CRS is to construct or adapt curricular tasks to be used with CRS (e.g., Beatty et al., 2006a; Kay & LeSage, 2009). The reason for this is that good CRS tasks often differ in format and functionality from ordinary tasks in textbooks or for tests (Beatty et al., 2006a), especially those aiming at engineering a mathematical classroom discussion. The most common format of CRS tasks is multiple-choice. A multiple-choice task is built on a stem, often including a question or statement and several answer choices. The correct choices are equal to the correct answer, while the other, “wrong”, choices are called distractors. Studies suggest that multiple-choice tasks for CRS use should have logical distractors built on common student misconceptions or mistakes (Caldwell, 2007; Crouch & Mazur, 2001; Kay & LeSage, 2009). Figure 4 shows an example of such a task.

![Figure 4. Example of a CRS task in multiple-choice format with distractors building on common misconceptions (Gustafsson & Ryve, 2016, p. 98).](image)

The specific tasks aiming at engineering mathematical classroom discussions should also be quite difficult, and produce a spread among students’ responses and focus on important concepts (Cline et al., 2013; Crouch & Mazur, 2001). Furthermore, research suggests that these CRS tasks should focus on analysis and reasoning rather than calculation and memory recall (Beatty et al., 2006a; Cline et al., 2013; Lim, 2011). One specific strategy when constructing discussion tasks in multiple-choice format for CRS use is to have multiple defendable answers, or no correct answer (Beatty et al., 2006a; Hodgen & Wiliam, 2011; Miller, Santana-Vega, & Terell, 2006). An example of this is when more than one answer can be correct, depending on the interpretation of the task. Figure 5, which follows, shows an example of a task with multiple defendable answers.
Another strategy found in literature on multiple-choice tasks that seek to engineer discussions is to write statements in the stem and let the students evaluate them. Figure 6 shows an example of such a task. These tasks should engineer a discussion in which the students are forced to explain, prove, and offer convincing arguments for their claims (Hodgen & Wiliam, 2011; Swan, 2005; 2007).

![Figure 6](image.png)

**Figure 6.** Example of a CRS task with a statement in the stem.

### 3.1.5 Support for teachers

As described earlier, there are some technical and personal challenges to overcome when implementing teaching supported by CRS. To overcome these challenges, teachers might need support. When reading and analyzing earlier literature, I identified three main areas of support for teachers implementing CRS in their classrooms: 1) professional development on CRS use; 2) adequate technical support; and 3) curriculum materials and task design (Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). According to Lee et al. (2012), professional development programs need to focus on teachers’ knowledge and skills for conducting classroom discussions, and they also suggest continuous long-term professional development to decrease the impact of teachers’ beliefs and low confidence level. Research (e.g., Kay & LeSage, 2009) reports that teachers struggle with the time and knowledge to develop good, effective CRS tasks for different purposes. There is obviously a lack of support for developing tasks as well as a lack of task collections, and in research there is also a lack of frameworks or design principles for this purpose (Beatty et al., 2006a). The participating teachers...
in King and Robinson’s (2009b) study identified the creation of a bank of relevant CRS tasks as one key requirement for CRS use.

3.2 Framework for analyzing technology integration

This section starts with a short description of different frameworks for technology integration in the classroom. This is followed by a deeper presentation of Ruthven’s (2009) framework, the Structuring Features of Classroom Practice (SFCP), which is explored in Paper II. The reason for this is to describe the rationale for exploring the SFCP framework, and also to offer the reader more knowledge about this framework.

The literature contains different frameworks that can be used for analyzing technology integration in teaching. One conceptual framework commonly used in research for mapping and analyzing teacher knowledge when integrating technology in teaching is Koehler and Mishra’s (2009) technology pedagogical and content knowledge (TPACK), formerly known as TPCK (Mishra & Koehler, 2006). TPACK is an extension of Shulman’s (1987) well known notion of pedagogical content knowledge (PCK). The core idea of the framework is to capture essential qualities of teacher knowledge for integrating technology into classroom practice.

Other researchers in mathematics education have used the theory of “instrumental orchestration” as a framework for analyzing teaching and learning supported by technology (cf. Artigue, 2002; Drijvers, Doorman, Boon, Reed & Gravemeijer, 2010; Drijvers & Trouche, 2008; Trouche, 2005). This theory focuses on a process of “instrumental genesis”, whereby a tool evolves into a functional tool; at the same time, the teacher evolves into a proficient user of the tool (Drijvers et al., 2010; Drijvers & Trouche, 2008; Trouche, 2005). Further, a more recently developed framework designed to support the identification and analysis of teachers’ professional knowledge for technology integration in the classroom is Ruthven’s (2009) SFCP framework. TPACK and “instrumental orchestration” are commonly used frameworks for analyzing technology integration in the classroom, but as Ruthven (2009) points out, the SFCP framework includes features of the importance of craft knowledge that other frameworks largely overlook. This is the main reason I decided to explore the SFCP framework in Paper II.

3.2.1 Structuring Features of Classroom Practice

According to Ruthven (2009), the SFCP framework takes a naturalistic approach with a focus on elements directly related to teachers’ classroom practice. Drawing on earlier research on teaching in general, Ruthven has built the framework based on five key structuring features of classroom practice. These features are working environment, resource system, activity format, curriculum script, and time economy. I will now describe these structuring
features and the associated craft knowledge related to technology integration.

3.2.1.1 Working environment
The working environment is the physical location where the teaching takes place. It includes technical infrastructure, physical layout, tools, materials and associated class organization and classroom routines. Teaching with technology often demands an adaptation of this working environment, for example reorganizing the classroom and establishing new routines. Other required teacher knowledge related to this feature includes organizing and managing student access to and use of tools and materials, organizing and displaying materials, and capturing student productions and converting them into digital form. Further, knowledge is required about managing transitions between lesson stages, especially if it involves moving students in or between different classrooms. (Ruthven, 2009; 2013, p. 12)

3.2.1.2 Resource system
Ruthven (2009) stresses that new technology increases the range of tools and materials available in classrooms to support teaching. This increase of resources creates a challenge for teachers in forming a coherent resource system of different and compatible elements that can function and complement each other. This resource system also requires that all participants, teachers and students, are capable of using the resources effectively. The teacher needs knowledge about establishing appropriate techniques and norms for the use of tools, managing old and new technologies alongside each other and coordinating the use of different tools. (Ruthven, 2009; 2013, p. 12)

3.2.1.3 Activity format
The activity format includes different types of formats for classroom action and interaction; these activity formats structure the activity and help organize the participants’ roles and how they act in different stages of the lesson. The teacher needs knowledge about grouping arrangements and establishing new (or adapting old) structures of interaction between students, teacher and technology. This feature also places demands on the teacher to establish appropriate roles for the students. (Ruthven, 2009; 2013, p. 12)

3.2.1.4 Curriculum script
Curriculum script is a concept first presented by Putnam (1987), who defines it as “a loosely ordered but well defined set of skills and concepts students were expected to learn, along with the activities and strategies for teaching this material” (p. 13). According to Ruthven (2013), it includes and “interweaves mathematical ideas to be developed, appropriate topic-related tasks to be undertaken, suitable activity formats to be used, and potential student difficulties to be anticipated, guiding the teacher in formulating a suitable lesson agenda, and in enacting it in a flexible and responsive way” (p. 13).
Ruthven (2009; 2013) claims that teachers integrating new tools and resources in their classrooms need to develop their curriculum script. The developed curriculum script is then needed for planning the teaching supported by technology. This requires that teachers have knowledge about recognizing and responding to different ways technologies can afford or constrain specific processes and objectives when students are learning a specific topic or content. This requires teacher knowledge about choosing or revising curriculum tasks to better meet the affordance of new tools, developing ways of using these tasks, and managing patterns of students’ responses (Ruthven, 2009; 2013, p. 12).

3.2.1.5 Time economy
According to Ruthven (2013), the integration and introduction of new technologies in the classroom may influence time economy. Ruthven (2013) defines time economy as “the frame within which lessons the time available for class activity is managed so as to convert it into ‘didactic time’ measured in terms of advance of knowledge” (p. 12). Teachers need craft knowledge about time economy in order to manage different ways of using tools to achieve increased student learning in return when investing time in new technology. Further, teacher knowledge is needed regarding fine-tuning all the other structuring features in order to increase the didactic return on time investment (Ruthven, 2009; 2013, p. 12).

3.2.1.6 Critique
The SFCP is a relatively new framework and therefore has not been exposed to much critique. Researchers have used the framework on empirical data in a few papers (Bozkurt & Ruthven, 2015; Ruthven, 2013) and found it useful for analyzing teachers integrating technology in the classroom. Ruthven (2013) points out that the framework’s different backgrounds of the five constructs might cause issues of coherence, stating that “such eclecticism is characteristic of the powerful intermediate theory that effective analysis of issues of teaching requires” (p. 13). Ruthven (2013) points out that further studies are required to elaborate and refine the framework.

3.3 Summary of the literature review
Research suggests that CRS has the potential to support teachers and improve learning and including that CRS can be a useful tool for engineering classroom discussions. Experience from research and practice has shown that a key factor when utilizing a CRS for engineering discussions is the use of suitable tasks. Research also suggests that CRS tasks in multiple-choice format that aim at engineering discussions should be challenging and have distractors that build on common student misconceptions or mistakes. This
literature has offered important input in the development of the design principles in Paper I. Furthermore, the SFCP framework is designed to support the identification and analysis of teachers’ professional knowledge for technology integration in the classroom. TPACK and “instrumental orchestration” are commonly used frameworks for analyzing technology integration in the classroom, but the SFCP framework includes features of the importance of craft knowledge that other frameworks largely overlook. The potential of this framework is explored in Paper II.
4 Methodology

This thesis is built on the work and the data from two macro-cycles in a design research project in which research and practice interacted (McKenney & Reeves, 2012; van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). This chapter focuses on the methodology and arguments for the methodological choices made in the research project. Further, the chapter starts with an elaboration on a socio-cultural perspective on tools for supporting teachers. Then, a description of the arguments for the choice of conducting educational design research is presented. Thereafter, the participants and context are presented. This is followed by a description of arguments for the choice of CRS. Then, the arguments and rationale behind the methodological choices in the two papers are described. Finally, ethical considerations, trustworthiness and a discussion on the methodology of the thesis are presented.

4.1 Tools for supporting teachers

In socio-cultural theories, tools play an important role (Säljö, 2014). According to Säljö (2014), these tools can be seen as intellectual or physical artifacts that we have access to and can interact with in order to understand our environment or to act in it. We do not stand in direct contact with the environment; in social practices, we use or interact with tools that mediate between the individual and the social (Säljö, 2014). Tools can be seen as mediators of activity (Radford, 2011). Both empirical research (Franke et al., 2007) and elaboration of theories (Wertsch, 2007) suggest that tools guide teachers in establishing classroom practices (Cobb & Jackson, 2012). In the mathematics classroom, tools like textbooks, tasks, digital technology and teacher guides are resources that can afford or constrain teachers in establishing different classroom practices (Stein, Remillard, & Smith, 2007). Therefore, I have chosen to focus on teacher resources such as CRS, tasks and frameworks. These are all important and central tools that can support teachers in establishing the social practices of mathematical classroom discussions. Firstly, the CRS is conceptualized as an important tool that mediates thinking and practices. It is a physical tool that mediates activities of posing, collecting and presenting tasks and responses between students, their peers, and the teacher. Technology enables different and new forms of inter-
activity (Säljö, 2014), and the CRS can change the way classroom communication occurs as it forces every student to be active and show his or her thoughts or reasoning, anonymously, on a shared screen. This can build a foundation for the social practice of conducting mathematical classroom discussions. Secondly, the frameworks in this study – the SFCP framework, the design principles and the task type framework – are all tools that teachers, curriculum developers and researchers can appropriate, and thus function as means to support both technology integration as well as the construction, selection and evaluation of tasks to be used in practice. Thirdly, from a socio-cultural perspective, the specific CRS tasks and the CRS itself are not simply tools that can be implemented in practice; they are also tools that reorganize the classroom practice. The tools in this study can function as a means to support teachers in establishing the practice of mathematical classroom discussions, including establishing associated and different roles for students and teachers.

4.2 Educational design research

The main focus and purpose of this research project was to develop design principles to be used with CRS in order to engineer mathematical classroom discussions. To achieve this, I chose to conduct an educational design research project. The work in the project has been characterized by an iterative and process-oriented approach in close collaboration between researcher and teachers, aiming at producing theory for research as well as practices and tools for influencing teaching and learning (Barab & Squires, 2004). The educational design methodology enabled me to develop and improve design principles (van den Akker et al., 2006) and task types for use in a technology-supported learning environment (Wang & Hannafin, 2005; Reeves, 2006). Consistent with van den Akker et al. (2006), design principles can be seen as heuristic statements that offer guidelines for achieving a specific goal in a specific context. Thus, in this project, design principles are guidelines for achieving the goal of generating CRS tasks aiming at engineering mathematical classroom discussions. As mentioned before, there seems to be a substantial lack of research on CRS use in secondary mathematics classrooms (Kay & LeSage, 2009), and especially on task design (Beatty et al., 2006a).

In a design research study, the intervention can play different roles in the research. According to McKenney and Reeves (2012), educational design research can be conducted on the intervention or through the intervention. In Paper I the research is on a specific aspect26 of the intervention itself. In Paper II, on the other hand, the research was conducted through the interven-

26 CRS tasks.
tion as the study did not aim to generate knowledge about the intervention itself, although it did have implications on the intervention (McKenney & Reeves, 2012).

4.3 Participants and context

All participating teachers worked in lower secondary school\textsuperscript{27} in one of Sweden’s largest municipalities. One teacher participated in Cycle 1, while in Cycle 2 six teachers working at the same school joined me in the project. The choice of teachers at these particular schools is partly due to the schools’ being one-to-one schools, where all students had access to their own laptop PC, and also the fact that during these academic years, I was a mentor to math teachers at these schools. This mentorship, part of a comprehensive municipal research and development project, meant that I had already established a good relationship with both the schools’ administration and teachers, which made it easier to conduct design research, in which researchers and teachers work closely together for a long time.

It is important to note that the teachers played a prominent role in the project. Their experiences and perceptions of the tasks’ effectiveness and usability, together with the research literature, served as crucial input in the iterative development of the design principles for CRS tasks (Paper I). The main rationale behind this choice of evaluating the intervention with the teachers’ perceptions is that teachers are central actors in the classroom, and should thus have their voices heard.

In Cycle 1 I worked with only one teacher. The rationale behind this choice was that another recruited teacher became ill and dropped out, and there was not enough time to recruit a new participant. Secondly, I thought it could be an advantage to work with one or few participants in the early stages of the development process, in order to have more time to obtain a deep understanding of the problem area. Further, the recruited teacher had a great deal of educational experience but no previous experience of utilizing a CRS in the mathematics classroom. The teacher received a short presentation on how to utilize a CRS.

One of the teacher’s two classes in Grade 8 was selected, by the teacher, to participate in the study. The teacher felt this class was more suitable to participate in the study, reasoning that its students were more likely to participate in discussions and interviews.

As stated in Chapter 2, we decided to develop and test different types of tasks that could support a formative assessment practice. However, the focus in the research was on tasks in multiple-choice format, aiming at engineering

\textsuperscript{27}Grades 6-9.
mathematical classroom discussions about important mathematical concepts and procedures.

The CRS tasks were implemented for eight weeks, while the class worked with the content of fractions and percentages. It was the time of the study that determined the choice of the mathematical content. The teacher’s planning of the content determined the choice of the duration of eight weeks. During this period, the teacher used and evaluated eight CRS tasks constructed to engineer a mathematical classroom discussion.

In Cycle 2, I chose to continue the work with six teachers at one school. The idea was to scale up the project in order to gather more data, develop the principles, and increase the transferability of the results.

To give the teachers an idea of how a CRS can be used in practice, I held a two-hour lecture on utilizing a CRS. This was followed by a two-hour workshop, where the teachers tested the chosen CRS software and discussed the following lessons. Together with the participating teachers, I planned and implemented the intervention in three lessons over a period of three months. Once again the topic of fractions was selected, due both to the teachers’ experience of students’ difficulties with fractions and to my experience of constructing CRS tasks for this topic. Further, the participating teachers’ perceptions of the learning progression of fractions guided the choice of content for the three lessons. The teachers selected, used and evaluated 23 CRS tasks constructed to engineer a mathematical classroom discussion.

4.4 Choice of classroom response system

There are both analog and digital response systems. With a bundle of cards, each displaying the letter A, B, C or D, students can hold up a card to respond to a multiple-choice task the teacher has launched. Another analog option is to have students write their responses on a mini-whiteboard and then hold the board up when responding to a task. The choice of response system must reflect the situation and the aim of the activity. The main reasons I chose to use a digital response system instead of an analog one was that it would allow me to: 1) collect, compile and display responses anonymously on a chart in real time; 2) keep the students anonymous to other students but known to the teacher; 3) automatically keep track of the students’ responses on a class, student and task level, which offers opportunities to analyze the results after the lesson and use this information to plan further teaching; 4) use the results of the analysis of the students’ responses to give delayed personal and group feedback; 5) analyze the students’ responses in multiple-choice tasks and improve the quality of the tasks by, for example, removing choices that no students chose; and finally 6) give automatic instant feedback. To summarize, these features of digital CRS can support the teacher in many ways in orchestrating discussions. Firstly, the results can be
used to decide whether or not to conduct a peer discussion before a whole-
class discussion. As stated before, research (Crouch & Mazur, 2001) has 
shown that students might benefit from a peer discussion if 30-70% of them 
have responded correctly to a task. Secondly, you can instantly, in a fast and 
smooth way, also display the results for all students, using a projector. The 
teacher can then let the students discuss the different choices they have se-
lected in a multiple-choice task.

We chose to work with a CRS software called Socrative\textsuperscript{28} for this project. 
The main arguments for this choice are: 1) it was free of charge; 2) I have 
previous experience with this particular software; 3) it was easy to manage; 
4) it was possible to monitor, save and analyze students’ results on class, 
student and task levels; and finally 5) it offered functions we desired, like 
adding pictures, choosing different task formats, adding written feedback, 
and creating multiple-choice tasks with several possible correct answers. The 
possibility to have items in which there are several equally correct options 
reduces the chances of students guessing correctly. For example, with five 
response options, when students do not know how many of them are correct, 
the probability they will guess correctly decreases from 20% to 3%, as op-
posed to when they know only one option is correct.

4.5 Methodological choices in Paper I

As stated earlier, the research in Paper I focuses on the development of de-
sign principles for constructing CRS tasks in multiple-choice format that can 
engineer a mathematical classroom discussion. This section starts with a 
short description of design principles, and the work made during the devel-
opment of these principles. Note that the final version of the design princi-
ples is presented in the result section. Thereafter, I describe the arguments 
for the use of different task types. This is followed by a presentation of the 
colleced data and the rationale behind the choices made. Finally, a presenta-
tion of the evaluation and quality improvement is provided.

4.5.1 Design principles

In this research project, the results and the knowledge claim are in the form 
of design principles (van den Akker, 1999). Design principles can be seen as 
heuristic statements that offer guidelines for a development process. These 
design principles can support others in choosing and applying the most suit-
able knowledge for the specific design and development of tasks to be used 
in their own settings (van den Akker et al., 2006). The format of the design 
principles, inspired by a format proposed by van den Akker (1999) and re-

\textsuperscript{28} \url{www.socrative.com}
vised by Tolboom (2012), consists of product characteristics and construc-
tion guidelines.

Based on the literature review in Cycle 1 a pilot of design principles was
formulated, aiming at constructing tasks for the purpose of engineering
mathematical classroom discussions. The principles were then revised before
and after the work in Cycle 2. The final version of the principles is presented
in Chapter 5 and in Paper I.

The design principles are a result in Paper I. Therefore, I choose not to in-
clude the principles and the arguments behind the revising of the principles
in this section.

4.5.2 Task type framework

To be able to develop the principles and better characterize good CRS tasks
in order to increase the possibility for the successful communication and
implementation of CRS tasks, the design principles were supplemented with
descriptions of generic task types. These task types were found in and select-
ed from earlier research (Beatty et al., 2006a; Hodgen & Wiliam, 2011;
Keogh & Naylor, 1999; Swan, 2005; 2007) on tasks that had shown the po-
tential to engineer classroom discussions in mathematics or science educa-
tion. Not all types had been tested and evaluated with support from CRS in
the context of mathematics education, so my contribution is that I brought
them together and evaluated them empirically.

These task types are a part of the result in Paper I and a more detailed de-
scription of the task type framework and examples of associated tasks can be
found in Paper I.

4.5.3 Data collection

As stated above, the teacher’s experience and perception of the tasks’ effec-
tiveness and usability, together with the research literature, served as crucial
input in the iterative development of the design principles. A great deal of
data were collected, from questionnaires, pre- and post-interviews, filmed
lessons and observations, reflection notes and student responses in CRS
tasks, but only the data used for the research are presented and discussed
below. When evaluating the tasks’ effectiveness, in both Cycles 1 and 2, I
relied a great deal on the teachers’ talk, reasoning and experience involving
using these tasks. The focus on teachers is a conscious choice, as in Swedish
classrooms ICT is often used to replace rather than strengthen teachers
(OECD, 2015). Teachers are extremely central actors in the classroom, and
we should therefore listen to them.

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29 For a fuller description of the development of the design principles, see Paper I.
In Cycle 1, three types of data were collected in order to increase trustworthiness. Firstly, so that the effectiveness of the implemented tasks could be evaluated, the teacher answered a number of evaluation questions in writing. I chose this method instead of an interview because I could not attend most of the lessons. The evaluation question used for the research focused on the tasks’ effectiveness in engineering a mathematical classroom discussion. Secondly, students’ responses to the CRS tasks were collected and compiled automatically in the digital response software program. The data were used to study the difficulty of the tasks and the spread among the answers. Research suggests that a spread among students’ answers is a prerequisite for a task’s ability to provoke a discussion (Cline et al., 2013; Crouch & Mazur, 2001). If there is little or no spread, this reflects that the students share the same opinion and that the tension needed to provoke a discussion is lacking. Thirdly, a semi-structured interview was chosen and conducted in an aim to elicit the teacher’s perceptions and experience of the intervention (Kvale & Brinkmann, 2009). An interview guide was constructed from different themes, including a focus on CRS use, and corresponding multiple-choice tasks. The guide contained an overview of the topics to be discussed and suggestions for open questions. During the interview, I proceeded from my starting questions and if necessary actively followed up on the teacher’s statements by requesting more information, clarification or extension, with the support of pre-written suggestions for follow-up questions. To increase the reliability of the interview, I sometimes asked control questions and on some occasions requested clarification of the respondent’s statements (Kvale & Brinkmann, 2009). The interview was audio recorded and then transcribed in NVivo 10.

In Cycle 2, once again different types of data were collected in order to increase trustworthiness. As in Cycle 1, the students’ responses to the CRS tasks were collected and compiled automatically in the software program. These data were used as input for conducting regular formative evaluations of the implemented tasks by studying the difficulty of the tasks as well as the spread among the answers. Further, after the lessons with trials of tasks in practice, I conducted a group interview in order to let the teachers evaluate the lessons and the quality of the intervention. I chose to conduct group instead of individual interviews for three main reasons: 1) this offered the possibility to develop a discussion that could yield a wider range of responses; 2) the project was also a development project whereby the teachers had implemented the same intervention, and a group interview gave them the opportunity to learn from each other; and 3) it was practical and time-saving (Cohen, Manion, & Morrison, 2011).

A semi-structured interview guide with evaluation questions was used to guide these interviews, in an aim to elicit the teachers’ perceptions and experiences of the intervention (Kvale & Brinkmann, 2009). The guide was built based on different themes, including a focus on CRS use and corresponding
multiple-choice tasks. I conducted the interviews with the same strategies described in Cycle 1, with the difference that I let other teachers respond to their colleagues’ statements. During the interview I tried to allow everyone to respond to the questions (Cohen et al., 2011) in order to avoid the dominance of any single respondent. All interviews were audio recorded and transcribed in NVivo 10.

As a complement to the group interviews in order to triangulate the data in Paper I, the teachers evaluated all implemented tasks’ effectiveness in engineering a mathematical classroom discussion, on a four-point Likert scale ranging from *not at all effective* to *very effective*. I chose an even number of points in order to force the teachers to take a stand (Cohen et al., 2011). The results from this task rating are presented in Paper I.

In addition to the interviews, a questionnaire with a four-point Likert scale rating was used to allow the teachers to evaluate the whole project. The questionnaire also contained ratings of the quality and effectiveness of the different task types, which were used to triangulate the data in Paper I. As for the task rating, I used the same range and an even number of points in order to force the teachers to take a stand (Cohen et al., 2011). The results of this task type rating are presented in Paper I.

4.5.4 Evaluation and quality improvement

In order to improve the quality of the design principles and the intervention, formative evaluation was conducted using Nieveen’s four quality criteria of relevancy, consistency, practicality and effectiveness (Nieveen, 2007; van den Akker, 1999). With respect to the relevancy criterion I evaluated, through a literature study and interviews, whether it was a need for discussion tasks to be used with CRS, and that the design was based on scientific knowledge. Considering the consistency criterion, I explored whether the task types and tasks were logically designed to be used with CRS, and whether they had the potential to engineer a discussion. This was achieved by checking the alignment between the task types, tasks and design principles. With regard to the practicality criterion, I evaluated the tasks’ usability in the classroom before the trial in the classroom through a screening and a group discussion. With the trial in the classroom, the actual practicality was evaluated using reflection notes, questionnaires and interviews. Considering the effectiveness criterion, using reflection notes, questionnaires and interviews I evaluated how well the use of CRS and the corresponding tasks resulted in a mathematical classroom discussion. Table 2 summarizes the selected evaluation methods and activities in Cycles 1 and 2 related to the different quality criteria.
Table 2. Selected evaluation methods and activities in Cycles 1 and 2 related to the different quality criteria (Gustafsson & Ryve, 2016, p. 92).

<table>
<thead>
<tr>
<th>Quality criteria</th>
<th>Cycle 1 Evaluation method and activities</th>
<th>Cycle 2 Evaluation method and activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance</td>
<td>Content validity</td>
<td>Literature study and interview with teacher</td>
</tr>
<tr>
<td>Construct validity</td>
<td>Checklist - alignment of tasks with design principles</td>
<td>Checklist - alignment of task type with design principles</td>
</tr>
<tr>
<td>Practicality</td>
<td>Expected</td>
<td>Screening</td>
</tr>
<tr>
<td></td>
<td>Actual</td>
<td>Trial with reflection notes, questionnaires and interviews</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Expected</td>
<td>Trial with reflection notes, questionnaires and interviews</td>
</tr>
<tr>
<td></td>
<td>Actual</td>
<td>Trial with questionnaires and interviews</td>
</tr>
</tbody>
</table>

4.5.4.1 Summative evaluation

After the implementation phases I conducted summative evaluations\(^{30}\), including a retrospective analysis of the collected data.

In Cycle 1, the findings from the interviews were triangulated with results from the reflection notes and the descriptive statistics from students’ responses in tasks. The knowledge and experience gained in this first macro-cycle were then used to adjust the design principles. The analyses and experiences from Cycle 1 produced three results useful in developing the design principles. Firstly, the design principles were reconstructed with respect to the task’s difficulty level. Secondly, the analyses implied that it was possible to construct good CRS tasks that do not focus on common mistakes or misconceptions. Thirdly, the analyses revealed that the teacher had difficulty characterizing the different types of CRS tasks. This, together with my own difficulties constructing good CRS tasks, made me draw the conclusion that the formulation of the design principles might be too vague. Therefore, I supplemented the design principles with descriptions of different task types that supported them. This task type framework therefore has a dual rationale: 1) to be able to better characterize good CRS tasks, and 2) to increase the possibility for the successful communication and implementation of CRS tasks in the classroom.

\(^{30}\) For a more detailed description of the evaluation, see Paper I.
When analyzing the data in Cycle 2, I calculated descriptive statistics on the ratings of the task types and tasks, including mean and standard deviation. The findings were then triangulated with results from the group interviews. The results of the analysis suggested that all tasks and task types engineered a mathematical classroom discussion according to the teachers’ perceptions, with one exception for a task categorized in a task type focusing on misconceptions and mistakes; for this task type the result is ambiguous.

Altogether, the data, analysis and experiences from Cycle 2 guided me to use the characteristics of the task types as important input when revising the design principles.

4.6 Methodological choices in Paper II

The research in Paper II focuses on exploring Ruthven’s (2009) SFCP framework. This section starts with the arguments behind the choice to explore this particular framework. Then, a description of the data sources and the context is presented, together with the rationale behind the choices made. Finally, a description of the data analysis is presented.

4.6.1 Why explore the SFCP framework?

As mentioned earlier, when analyzing the data in Paper I I found indications that there are several aspects that influence successful CRS integration in the mathematics classroom. The teachers reasoned about many different challenges during the interviews. I believed these challenges provided a useful case for exploring the potential of Ruthven’s (2009) SFCP framework. Further, I believed this framework might be useful as an analytical tool to help me better understand my data.

The SFCP framework is a relatively recently developed framework for analyzing and identifying critical aspects of technology integration in the mathematics classroom (Ruthven, 2009). TPACK (Koehler & Mishra, 2009) and the theory of “instrumental orchestration” (Drijvers et al., 2010; Drijvers & Trouche, 2008; Trouche, 2005) are commonly used frameworks for analyzing technology integration in education, but as Ruthven (2009) stresses, the SFCP framework includes aspects like the complexity and importance of craft knowledge that TPACK and other frameworks overlook. This is the main reason I decided to explore the SFCP framework. A second reason is that the SFCP framework is a rather young framework and thus needs to be tested with empirical data from other contexts (Ruthven, 2009).
4.6.2 Data sources and context

Ruthven’s (2009) SFCP framework was tested on empirical data from the two cases\(^{31}\) in this design research project. The chosen data sources to be analyzed consisted of one interview with the participating teacher in Cycle 1, who worked with students in Grade 8, and a group interview with six teachers in Cycle 2, who worked with students in Grades 6-9. There are three main arguments for choosing these sources and the context of CRS and Sweden: 1) the framework had not yet been tested on CRS data or on data from education in Sweden; 2) in recent years, CRS has become a rather common tool in lower secondary schools; and 3) the data collection was not based on the framework. When the data collection is not based on the framework this offers a better opportunity to investigate what it does not capture, whereas an interview or questionnaire based on the framework places the focus on the aspects already included in it.

4.6.3 Data analysis

The interview data were used as a means to explore the potential of the SFCP framework as a tool for analyzing empirical data in order to conceptualize and analyze teachers’ reasoning about CRS integration in the mathematics classroom. To support this exploration, two analytical questions were used:

1. How much of the teachers’ reasoning ends up in the various categories in the SFCP framework?
2. Are there parts of the interviews that do not fit in the categories of the SFCP framework? If so, does a new theme emerge?

To answer these questions, I conducted a content analysis with systematic quantification (Kvale & Brinkmann, 2009). In this analysis (Bryman, 2012), text segments of the interview transcriptions were coded in NVivo based on the categories in the SFCP framework. The text segments in every category were then brought together and a narrative was written; see Paper II for more details.

4.7 Ethical considerations

In this section I present ethical considerations in relation to my study. During the work on this research project I have followed the Swedish Research Council’s (2011) ethical guidelines.

In this project I worked in close collaboration with teachers. This means that I, as a researcher, sought to create a good climate where everyone con-

\(^{31}\) Case 1 was the case in Cycle 1, and Case 2 was the case in Cycle 2.
tributed their expertise and where everyone’s expertise was respected. As researcher and initiator, I also had a responsibility concerning the quality of the ideas and tools that were tested in the classroom, and for ensuring they had the possibility to support the teachers in their ambition to develop the students’ knowledge.

The research project was conducted in schools that were taking part in a larger research and professional development program, of which my project was a part. The recruited teachers were informed about the project, including information about its aim, how they would be involved, that their participation was voluntary, and that the collected data would be used for research purposes only. Information about the project was also given to the school’s principal. At the first physical meeting with the students, they were also given information about the study and told it would be part of a licentiate thesis. Afterwards, the students had the opportunity to ask questions. They were also informed that the data would be collected and that this was for research purposes only, that the results may be published in journals and the thesis, and that all publication would be done without mentioning the names of the school, teachers or students. Regarding informed consent for the students, their parents received information about the research project in a letter, which they were to sign in order to consent or dissent to their child’s participation. The letter also included contact information in case they had any questions.

I have kept the participants’ identities confidential during the research process. No original names, schools or city can be found in the questionnaires, interview transcriptions or papers of this thesis. All data have been handled with care to prevent anyone outside the research group gaining access to them.

4.8 Trustworthiness

In order to discuss the trustworthiness of the results in this thesis, I have chosen to use Bryman’s (2012) four criteria for assessing qualitative research: 1) credibility; 2) transferability; 3) dependability; and 4) confirmability. The argument for using these criteria instead of validity and reliability is that I regard the results of this thesis as building mostly on qualitative data.

To increase credibility, different types of data have been used. In Cycle 1, reflection notes and interview data were triangulated. In Cycle 2, group interviews were supplemented with questionnaires. During the implementation phase, evaluations of the efficiency of tasks in so-called micro-cycles were conducted after every trial in the classroom. These evaluations and the tasks’ efficiency were then discussed with the teacher in order to increase credibility.
The *transferability* in Paper I has been strengthened by using the results from Cycle 1 to revise the design principles and then evaluate them, the task types, and the associated tasks at another school with six teachers in Cycle 2. In Paper II, the framework was tested on two different types of data in order to increase transferability. Further, in this thesis I have also tried to offer detailed descriptions of the study and context in order to allow readers to make their own judgment as to its possible transferability (Bryman, 2012).

Regarding *dependability*, I have tried to explicitly describe the rationale behind the design and choices I made during the research process. Triangulation was used, and the results have been discussed with supervisors and colleagues.

Concerning *confirmability*, throughout the research process I have tried to be as objective as possible and not let my assumptions and preconceptions affect my conducting of the research.

### 4.9 Discussion of the methodology

In this design research study, as a researcher I have played an active role. Through the intervention, the design of lessons and implemented tasks affected the teachers’ behavior and teaching. Therefore, I had to be aware of and reflect on how my role as an active researcher can affect lessons, observations, analyses and interpretations in order to produce reliable results.

The results in Paper I build on the perceptions of seven teachers. Although teachers’ perceptions are important to consider when constructing tasks, this study cannot claim that the results can be generalized. More research is needed in other contexts, for example another area of content, and on a larger scale to be able to better validate and generalize the results.

In Paper II the SFCP framework is tested and evaluated on data generated from this research project with two cases in the context of lower secondary schools in Sweden. The framework and the results of Paper II need to be further investigated with empirical data from similar or other contexts.

It is difficult (McKenney & Reeves, 2012) to conduct a design research project with the double pursuit of theory-building and practical innovation. As a researcher, besides knowledge of good research ethics and knowledge of research, I need to have knowledge of a variety of evaluation, sampling and analysis methods and apply these in various parts of the research process. I also need to be creative and able to cooperate with others. Additionally, I need to be sustainable and able to work with many different things at the same time, and for a long time. So there are many parts of the work in this complex research project that could have been done better, or avoided completely, as well as things that should not have been done. I will describe two main issues based on the methodology.
Firstly, the research project would have benefited from a larger research team, including researchers with different types of expertise to be used at different stages of the project. Having a larger research team would have offered the possibility to collect, use and analyze more data instead of only basing the results on teachers’ perceptions. For instance, to be able to even better determine the potential of CRS tasks seeking to engineer a mathematical classroom discussion, supplementary analysis of video recordings from the classrooms would have been useful.

Secondly, the results are mostly based on data from interviews with the teachers. As mentioned earlier, the main argument for this choice is that teachers are central actors in the classroom, and we should thus listen to them. Just as Kvale and Brinkmann (2009) point out, interviewing requires a craft knowledge, and this skill is best attained by conducting interviews and carrying out transcriptions. During the work with the transcriptions I realized how easy it is to ask leading questions and to fail to ask those important follow-up questions, even with a well-written interview guide.
5 Summary of the papers

This chapter includes summaries of the two papers included in this thesis. The summaries focus mainly on the results.

5.1 Paper I

Title: Developing design principles and task types for classroom response system tasks in mathematics: Engineering mathematical classroom discussions.

Authors: Gustafsson, P., & Ryve, A. (2016).

This paper reports on results from two cycles in a design research project establishing mathematical classroom discussions with support from a classroom response system (CRS). The aim of the paper is to develop design principles and task types for CRS tasks in mathematics that aim to engineer these mathematical classroom discussions. The study generated three design principles, six task types, and 31 empirically evaluated tasks, which can be useful in choosing, evaluating and constructing CRS tasks in classroom practice. These design principles\(^{32}\) are the main result from this paper (p. 104).

\[\text{DP1} \quad \text{If you want to construct CRS tasks in multiple-choice format aiming to engineer mathematical classroom discussions that mainly concern students’ conceptual understanding, you are best advised to create a challenging task with a) statements in the stem, b) fictitious answers, c) multiple defendable answers, and/or d) choices that belong together except one, as these tasks can force the students to evaluate, discuss and reason about important concepts (Beatty et al., 2006a; Cline et al., 2013; Crouch & Mazur, 2001; Hodgen & Wiliam, 2011; Keogh & Naylor, 1999).}\]

\[\text{DP2} \quad \text{If you want to construct CRS tasks in multiple-choice format aiming to engineer mathematical classroom discussions that mainly concern students’ understanding of procedures,}\]

\(^{32}\) DP1 = Design Principle 1
you are best advised to create a challenging task with choices displaying different possible solutions, as these tasks can force the students to analyze, discuss and reason about the effectiveness and/or correctness of these different strategies and methods (Crouch & Mazur, 2001; Swan, 2005; 2007).

If you want to construct a CRS tasks in multiple-choice format aiming to engineer mathematical classroom discussions about students’ misconceptions or common mistakes, you are best advised to create a challenging task and build distractors on typical misconceptions or mistakes, as this offers the opportunity to conduct discussions that can force the students to discard or decrease these misconceptions or mistakes (Cline et al., 2013; Crouch & Mazur, 2001; Haldyn et al., 2002; Kay & LeSage, 2009; Lim, 2011; Miller et al., 2011; Wit, 2003).

In addition to the design principles, a task type framework was developed including six task types: *Who is right?*, *Odd one out*, *Multiple defendable answers*, *Evaluating statements*, *Trolling for misconceptions or mistakes*, and *Evaluating solutions*. The task types were selected from research (Beatty et al., 2006a; Hodgen & Wiliam, 2011; Keogh & Naylor, 1999; Swan, 2005; 2007), and my contribution is that I brought them together and tested and evaluated them in the context of CRS and mathematics in lower secondary school in Sweden.

The empirical evaluation suggests that teachers consider the CRS tasks constructed from the design principles and the task types to be useful in engineering mathematical discussions in secondary school mathematics classrooms. The study supports earlier findings in research that suggest that CRS and appropriate tasks are a useful way of establishing productive classroom practices (e.g., Beatty et al., 2006a; Cline et al., 2013; Crouch & Mazur, 2001; Miller et al., 2006). The main contribution of the article is its theoretical work in combining research results from several studies to formulate design principles and task types, and empirically evaluating them in practice together with teachers.
5.2 Paper II

Title: Exploring a framework for technology integration in the mathematics classroom.

Author: Gustafsson, P. (2016).

In Paper II, the data used came from two cases in a design research project in lower secondary school in Sweden that implements mathematical classroom discussions with support from a classroom response system (CRS) and associated tasks. The aim of the paper is to investigate the potential of Ruthven’s (2009) framework, the Structuring Features of Classroom Practice (SFCP), as a tool for analyzing empirical data in order to conceptualize and analyze teachers’ reasoning about technology integration in the mathematics classroom.

The SFCP framework captured a total of 90% of the teacher’s reasoning in Case 1 and 65% of the teachers’ reasoning in the group interview in Case 2. Table 3 shows that all features of the framework captured some parts of the teachers’ reasoning in both cases. The largest parts were related to features of activity format, curriculum script and resource system. Note that some parts were coded in several categories, and figures are rounded.

Table 3. The SFCP frameworks coverage of teachers’ reasoning in the interviews (p. 122)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Working environment</th>
<th>Resource system</th>
<th>Activity format</th>
<th>Curriculum script</th>
<th>Time economy</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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</table>

However, when the parts that the framework did not capture were analyzed, a clear theme emerged. Most of the teachers’ reasoning not captured by the framework was related to students’ attitudes and behaviors. For example, teachers reasoned about students eager to discuss the CRS tasks and difficulties handling students who wanted to respond quickly and could not wait for their peers to finish thinking. They also reasoned about difficulties with students who did not want to participate, especially in the discussions, during which they simply sat quietly.

The main contribution in Paper II is its investigation of the potential of the SFCP framework as a tool for analyzing empirical data in a context of CRS use in lower secondary schools in Sweden. However, the conceptualization of teachers’ reasoning in this study could also contribute to the knowledge about utilizing a CRS in the mathematics classroom.
6 Conclusions and discussion

This final chapter of the kappa starts with conclusions regarding the results of the two papers in this thesis. This is followed by a discussion of critical aspects for CRS integration in the mathematics classroom. Thereafter, contributions to research, practice and practitioners are discussed. Finally, I offer suggestions for further research.

6.1 Conclusions

The task type framework of generic task types in Paper I offered important support in choosing, constructing and evaluating CRS tasks, and through the tested and evaluated task types, several new characteristics of good tasks were derived. These characteristics served as important input in the final revision of the design principles. For example, the task types *Who is right?* and *Evaluating solutions* were highly valued by the teachers. Both elicit fictitious student answers, often including common errors or mistakes. Paper I also concluded that multiple defendable answers entail one useful characteristic that should be included in the principles, but as the participating teachers also stressed, you cannot always have multiple defendable answers. You also need to use similar tasks with only one correct answer, if students are to stay alert and analyze task choices carefully.

Paper II concluded that Ruthven’s SFCP framework can be useful as an analytical tool for conceptualizing and analyzing teachers’ reasoning about technology integration in the mathematics classroom in the context of CRS and Sweden. Still, the framework did not capture the teachers’ reasoning about students’ attitudes and behaviors, which were a challenge for the teachers integrating CRS in their mathematics classroom. Therefore, Paper II concludes that if, as Ruthven (2009) stresses, the SFCP framework aims at capturing key features of classroom practice and is to be built on a system of constructs closer to the ‘lived world’ of teacher experience and classroom practice, it would benefit from an extension and from taking into consideration students’ attitudes and behaviors.
6.2 Critical aspects of CRS integration

Building on earlier research, the results of the content analysis in Paper II and the results and conclusions from the papers in this thesis, discussions of critical aspects including the challenges facing, and support for, teachers wanting to integrate CRS in the mathematics classroom are presented here.

I have chosen to structure this section according to Ruthven’s (2009) components in the SFCP framework.

6.2.1 Working environment

The participating teachers in the two cycles mentioned three main challenges related to their working environment: 1) students who do not bring their computers or have nonfunctioning devices, 2) unreliable access to the Internet, and 3) the projector screen blocks a large part of the whiteboard surface. The first two challenges, related to students’ computers and the Internet accessibility, placed extra demands on the teacher in conducting the lesson in a smooth and meaningful way. These findings support earlier findings pointing out that the need for teachers to manage students’ lack of or nonfunctioning devices is a common challenge (Kay & LeSage, 2009). The teachers could not solve the nonfunctioning computers or the unreliable accessibility to the Internet. To support them in dealing with these challenges, the school needs to offer adequate technical support (King & Robinson, 2009b; Lee et al., 2012). However, the teachers might need an advance plan to encounter these challenges. A solution that arose in the interviews was that some teachers let students who did not have a functional computer or who were having trouble with the Internet connection work with a peer. Another solution was to let the students use their own personal smartphone.

The third issue is a challenge related to the projector screen: when pulled down, it blocks a large part of the whiteboard surface. When writing student solutions to or explanations of CRS tasks on the whiteboard, the teacher has to pull the projector screen up and blacken the computer projection, and then pull the screen down again to continue with the CRS tasks. In this particular classroom, it was not possible to look at both the task and the students’ solutions at the same time. This could constrain the possibility to teach with the support of CRS and conduct a mathematical classroom discussion. This issue is not mentioned in earlier research. One reason for this might be that the research has often been conducted in higher education (Kay & LeSage, 2009), in large classrooms. At any rate, if there is no possibility to have more space for a whiteboard or teach in a larger classroom, the teacher needs to have a plan for handling this issue. One solution that was discussed involved taking photos of students’ written solutions or explanations and displaying them on the shared projector screen with the computer.
6.2.2 Resource system

I will now present and discuss two main challenges relating to teachers’ craft knowledge associated with the resource system. Firstly, some of the teachers struggled with using the software. For example, they launched the tasks in the wrong mode, so the students had access to all tasks at once and had to interrupt the whole activity. This supports earlier findings in research that point out that technical problems comprise one of the most common challenges for teachers integrating CRS in their teaching (Beatty et al., 2008; Caldwell, 2007; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012;), and that teachers’ utilization of CRS is affected by their skills and knowledge involving the software (Kay & LeSage, 2009; Lee et al., 2012). In this project, two teachers immediately performed a new trial with other classes and succeeded in launching the tasks in the correct mode. This finding supports results in earlier research that suggest that these technical problems decrease over time as the teachers become more comfortable with the CRS (Beatty et al., 2008). Further, the teachers emphasized the importance of the possibility to try out the software and the different modes before the lesson; and teachers might need adequate technical support to resolve these technical problems (Beatty et al., 2008; Caldwell, 2007; King & Robinson, 2009b; Lee et al., 2012). As in one of the cases in this study, this support could come from a more experienced colleague. This stresses the importance of collegial learning, with teachers planning, discussing and evaluating their teaching together.

Secondly, all interviewed teachers mentioned students’ access to paper and pencil during their work with CRS tasks that were to engineer discussions. One teacher felt that students did not need paper and pencil before responding to the tasks, but that it could be useful afterwards if they were to proof or argue about their, or others’, answers. Other teachers felt it could be useful to the students to have constant access to paper and pencil in order to structure their thoughts before answering a CRS task. The teacher in Cycle 1 said that students had a resistance to working out solutions to CRS tasks on ordinary paper before submitting an answer in the software program. According to the teacher, this constrained the possibility to identify and see students’ reasoning behind their answers before the discussion. In order to deal with this issue, the teachers in Cycle 2 agreed on the importance of making it clear to students whether they are allowed to, or required to, use tools like paper, pencil or calculator when working with CRS tasks. This solution does not answer the question of whether the students should or should not use these tools during the CRS work. However, the main idea of CRS tasks aiming at engineering a mathematical classroom discussion is to reveal how students think during the discussions, so it might not be important to demand that they write their solutions down for every task. But, as one teacher pointed out, some students might need paper and pencil in order
to structure their thoughts before answering a CRS task. At any rate, the teacher and students need to manage and coordinate the use of these tools.

6.2.3 Activity format

The most commonly used activity format in this research project followed the Peer Instruction method (Crouch & Mazur, 2001): 1) students think alone, 2) students respond to the task; 3) if necessary, conduct a peer discussion and then let the students respond again; and finally 4) conduct a whole-class discussion. According to the teachers, it takes a great deal of time to work with CRS tasks aiming at engineering discussions using this activity format. This finding supports earlier research results that have stressed that time is one of the greatest challenges facing teachers utilizing a CRS (Beatty et al., 2008; Caldwell, 2007; Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012), and that especially class discussions are time-consuming (Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). The time-consuming issue of conducting discussions was more serious for the teacher in Cycle 1 than those in Cycle 2. I suggest that this is due to the differences in the two cycles, whereby the teachers in Cycle 2 changed their activity format by using a flipped classroom method in order to gain more time to conduct discussions in the classroom. This is one of the main ideas of the flipped classroom method, with students watching video lectures at home and the teaching in class including more interactivity, problem-solving and practice exercises (Bishop & Verleger, 2013). The flipped classroom method could be one solution to the issue of little available time for conducting mathematical classroom discussions supported by CRS.

Further, the teachers also discussed how much time students need before answering a CRS task. This finding supports earlier research that suggest that this is a challenge for teachers integrating CRS technology in the classroom (Feldman & Capobianco, 2008). Some of the teachers let the students take as much time they wanted, which led to other students having to wait a number of minutes. No suggestions for a solution to this issue were found in the interview data, or in the literature. At any rate, the teacher needs to have a plan for dealing with this issue and have a sense of how demanding the tasks are. At the same time, the teacher needs to be sensitive to signals from students thinking and working on a solution, and then make a decision when to force every student to respond to the task. However, the main idea of the tasks is to reveal and advance students’ thinking through the discussions. Therefore, the students need to have thought through the task before responding, but do not necessarily need to have formulated a complete solution to it, in order to participate in and contribute to the discussions.
6.2.4 Curriculum script

Analyses of teachers’ reasoning in the interviews revealed two main challenges related to their curriculum script: 1) the orchestration of whole-class discussions, and 2) task design.

Firstly, the participating teachers realized and stressed that it is hard to conduct whole-class discussions building on students’ responses to CRS tasks. Research has shown that conducting whole-class discussions that elicit and extend students’ thinking is not easy (e.g., Franke et al., 2007; Kay & LeSage, 2009; Larsson, 2015; Lee et al., 2012). According to Lee et al. (2012), teachers’ use of whole-class discussions is affected by their knowledge and skills concerning orchestrating whole-class discussions. First, they need to understand the students’ thinking based on the CRS responses and make a decision as to whether to conduct a peer discussion or whole-class discussion, or simply move on. The use of the Peer Instruction method supported the teachers in Cycle 2 in making this decision. Crouch and Mazur (2001) suggest that if 30-70% of the students answer the task correctly, they will benefit from a peer discussion. If less than 30% or more than 70% of them respond correctly, they will not benefit from a peer discussion (Crouch & Mazur, 2001). Crouch and Mazur (2001) suggest that, in the former case, the students’ knowledge is too low for them to benefit from a discussion. In the latter case their knowledge is too high, so they do not need to participate in a peer discussion. In this case teachers could immediately conduct a whole-class discussion to elicit, support, and if possible extend the students’ thinking. Secondly, teachers need to conduct the whole-class discussion in a favorable way in order to both understand and advance the students’ thinking. According to Fraivillig et al. (1999, p. 155), teachers can encourage students to 1) analyze, compare and generalize concepts, and 2) consider and discuss interrelationships among concepts in order to extend their thinking. To implement these instructional moves, teachers can use questions (Boaler & Brodie, 2004). In the interviews, one teacher stressed the importance of having a clear teaching strategy for every CRS task to improve the quality of the whole-class discussion. However, to support teachers using curriculum materials, a teacher guide is useful (Ball & Cohen, 1996). I therefore suggest that constructed CRS tasks also include a teacher guide in order to support the teacher, as in the case of Cycle 2 in which the teachers were supported by a guide containing aim, solution, teaching strategies, discussions of the distractors building on common misconceptions or mistakes, and suggestions for follow-up questions in order to extend the students’ mathematical thinking.

The second challenge related to teachers’ curriculum script relates to the selection, adaptation or construction of good CRS tasks. This was not a great challenge for the teachers in this research project, as they received help from me as a researcher in delivering the CRS tasks; however, research has shown
that this is one of the major challenges involved with teaching with CRS (e.g., Lee et al., 2012). Nevertheless, the teacher in Cycle 1 said she would probably use CRS tasks more often if it were not so difficult and time-consuming to construct good tasks.

The results in Paper I suggest that these tasks may entail a challenging multiple-choice task with a) statements, b) fictitious answers, c) multiple defendable answers, d) choices that belong together except one, e) different possible solutions presented, and/or f) distractors building on typical misconceptions or mistakes. With support from the empirical data in my study, I suggest that the design principles and task type framework developed in Paper I could serve as valuable support for teachers in choosing, adapting and constructing CRS tasks.

Further, the design principles in Paper I point out that CRS tasks should be challenging for students. This builds on the idea that challenging tasks produce a spread in students’ answers. Research suggests that this spread may be an important factor in engineering a classroom discussion (Cline et al., 2013; Crouch & Mazur, 2001). As discussed above, if the tasks are too easy or too demanding, the class does not benefit from a peer discussion or a whole-class discussion. This suggests that every task needs to fit the different levels of knowledge in a class, as is the case with all tasks used in the classroom. And, as a consequence, teachers need to have good knowledge of both the class level and task design in order to choose, adapt or construct an appropriate task.

6.2.5 Time economy

A teacher in Cycle 2 said she would continue using CRS, although it takes time to prepare. She also said that “it’s worth the time because it activates every student...just like when I activated one student who usually doesn’t participate she said ‘ahaaa’ in front of the whole class. It was amazing”. This finding strengthens earlier research results that suggest that the “rate of return” may increase when CRS tasks are used (Caldwell, 2007), as well as research stressing that it is time-consuming to construct CRS tasks (King & Robinson, 2009b; Lee et al., 2012). Further, a challenge mentioned by the teachers related to time economy is that a classroom discussion in relation to CRS tasks takes up a great deal of lesson time. This challenge has been observed and discussed in earlier research (Kay & LeSage, 2009; King & Robinson, 2009b; Lee et al., 2012). If teachers choose to utilize a CRS and invest in time, it is important that this gives students good opportunities to increase their learning. In order to achieve increased student learning, many teachers need support in the form of curriculum materials, professional development, and technical support (King & Robinson, 2009b; Lee et al., 2012).
6.3 Contributions

This design research study aims to contribute to research, practice and participants, although the research contribution is the focus in this thesis.

This thesis contributes to research, offering knowledge about different sources of support for teachers integrating CRS in the mathematics classroom. Firstly, the results in Paper I contribute to knowledge about CRS task design, for tasks aiming to engineer mathematical classroom discussions. This knowledge contribution is formulated in the form of design principles and an associated task type framework containing characteristics of specific multiple-choice tasks. These principles and task types can support others in choosing and applying the most suitable knowledge for the specific design and development of CRS tasks to be used in their own settings (van den Akker et al., 2006). Secondly, Paper II provides an empirical test of the usefulness of the relatively newly developed SFCP framework (Ruthven, 2009) as an analytical tool for conceptualizing teachers’ reasoning about technology integration. Thirdly, the kappa of this thesis contributes to the knowledge about critical aspects, including challenges and support, for teachers integrating CRS technology in their mathematics classroom.

The teaching methods, design principles, task types and concrete tasks presented here can be directly useful for teachers wanting to establish mathematical classroom discussions supported by CRS and specific tasks. The design principles and complementary task types offer teachers a solution to one of the main challenges they encounter when integrating CRS in the classroom.

This study has also made a direct contribution to the participating teachers, although this was more related to the aim of the development project than the research project. Through their cooperation with the researcher during the whole project, the teachers have participated in lectures and discussions and have planned, tested, and evaluated the teaching supported by CRS and associated tasks. This work has made a contribution to their professional development.

6.4 Further research

During the work in Cycle 1, I also constructed a prototype of design principles, as well as tested and evaluated CRS tasks aimed at evaluating the teaching and getting information about students’ knowledge in order to make better decisions regarding the next step in the teaching. In the post-interview, the teacher expressed that these tasks had made a contribution to both the teaching and learning, so one interesting direction for further research could be to focus on the development and usefulness of such design principles and complementary CRS tasks. These types of tasks could also be seen as a short
test for students, and psychology research (Kubik, 2014) has shown that students might benefit from taking tests on a regular basis. According to Kubik (2014), this helps students reduce their forgetting rate.

Further, another natural and obvious suggestion for further research is to continue working on the results in Paper I and conduct research on a larger scale in order to refine or adapt the design principles and, if possible, be able to better generalize the results.

Finally, there is a lack of research in elementary and lower secondary school, and especially of comparative studies exploring the effects of CRS use (Hunsu et al., 2016). Thus, a comparative study including student pre-test and post-test, investigating the effects of CRS with three groups of students – 1) a group exposed to a digital CRS and specific task; 2) a group exposed to the specific tasks and an analog CRS system; and 3) a control group, using no specific tasks and neither a digital nor an analog CRS – would contribute a great deal to the knowledge about the effects of CRS use in the mathematics classroom.
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References


