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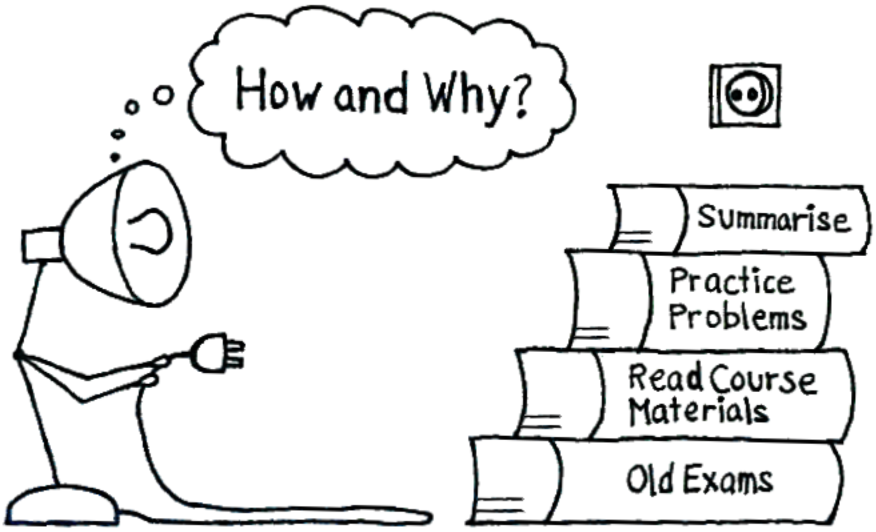

Learning strategies of engineering students

How do they study outside class, and why?

Master's thesis in Learning and Leadership

MARIA CERVIN-ELLQVIST
DANIEL LARSSON

Department of Communication and Learning in Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

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Department of Communication and Learning in Science
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone +46 (0)31-772 100

Abstract

While lecturers in engineering education may control what happens in class to promote students' learning, what happens outside class is up to the students themselves. One important factor of what happens outside class is which learning strategies students use, as some strategies are more effective than other. Another important factor is to which extent students self-regulate their learning by attempting to monitor, regulate and control it, which includes choosing learning strategies, using them and evaluating them. This regulation can for example include strategies aimed at increasing knowledge (cognitive strategies) or monitoring knowledge (metacognitive strategies).

This thesis aimed to (1) map what learning strategies engineering students use in a real-world setting, in real courses; (2) investigate the students' motivation for choosing certain learning strategies and (3) probe their metacognitive awareness of the effectiveness of different learning strategies. It also aimed to investigate if differences could be seen across two engineering programs (bio- and civil engineering) or across two types of courses (calculation courses and conceptual courses). To obtain insight into this, 416 students answered a questionnaire specifically designed for this study.

Our results revealed a complex picture of what learning strategies students use and why. It also revealed that the learning strategies students used varied across courses but not across programs. Further, the students used the strategies, including the most used strategy *to study old exams*, in several different ways. For example, they used them aiming at either cognitive or metacognitive goals or sometimes both. The participants were in general also found to be metacognitively aware of the effectiveness of different strategies. Some students, however, used certain strategies not because they believed them to be effective or aiming at cognitive or metacognitive goals, but to self-regulate their motivation or behaviour.

We can conclude that students used their strategies for a number of different reasons and in many different ways, which was not revealed by looking only at what students did. This points out that it is crucial to not only investigate what students do, but also why and how.

Keywords: learning strategies, self-regulated learning, metacognition, engineering education

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Maria Cervin-Ellqvist and Daniel Larsson
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1 Introduction

Students use various learning strategies when they study. The term strategy can be described as a plan of action that is executed in order to accomplish a goal. Therefore, a learning strategy can be considered a plan of action that students employ in order to reach their learning goals (Schmeck, 2013). According to Paimin, Hadgraft, Prpic, and Alias (2017), it is generally considered that learning strategies comprise motivation, affect, cognition, metacognition, and behaviour in order to increase the likelihood of learning, creating memories that are meaningful and retrievable, and carry out tasks of a higher cognitive order, for example problem solving. Examples of learning strategies are reading notes, doing practice problems and testing oneself.

The effectiveness of different learning strategies vary; not all strategies are effective (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013), and previous research has shown a difference between high and low performing students' choice of learning strategies (Duff, 2004; Ferla, Valcke, & Schuyten, 2008; Yip, 2009). Research has also shown that students' choice of strategies depends on the learning situation, where the students adapt their choice of strategies in order to actively take part in the learning process (Schmeck & Geisler-Brenstein, 1989). However, the students' choice of strategies can be changed with deliberate teaching of specific cognitive and metacognitive strategies that can, when applied consciously, result in increased learning (Bielaczyc, Pirolli, & Brown, 1995). While lecturers in higher education might control what happens in class to promote learning to a relatively high extent, what happens outside class is up to the students themselves. An important part of what happens outside class is to which extent students self-regulate their learning by attempting to monitor, regulate and control it (Pintrich, 2000). This includes choosing learning strategies that are effective to achieve the students' goal, contextual features taken into account (Pintrich, 2000). It should because of these reasons be of great interest to both universities and individual lecturers to investigate what learning strategies their students use, why they use them, and how aware they are of the effectiveness of their strategies, to be able to support the students.

Lecturers and universities must first establish what strategies are currently used to be able to help students employing effective learning strategies. When doing that, context should be considered as it may affect how students study (Hadwin, Winne, Stockley, Nesbit, & Woszczyna, 2001; Van Etten, Freebern, & Pressley, 1997). Some research has been done on engineering students learning strategies in language learning (Afshar, Moazam, & Arbabi, 2014; Granescu & Literat, 2013). Other studies have investigated psychology students' learning strategies (Carrier, 2003; Gurung, 2005; Gurung, Weidert, & Jeske, 2010). However, there seem to be very little research on engineering students learning strategies in STEM[1]-courses. The few studies found has had slightly different focuses, with one focusing on how certain strategies affected performance (Grohs, Knight, Young, & Soledad, 2018), and another on how students use of strategies changed over time in response to an intervention (Lawanto & Santoso, 2012). Previous research in other contexts in higher education has also not investigated why students use

[1] STEM stands for Science, Technology, Engineering and Mathematics

strategies, or how they actually use them. This should be of importance as one strategy might be used in several different ways and for different purposes (see for example Wissman, Rawson, and Pyc (2012) on students' use of flashcards). Further, very little research was found on students' awareness of the effectiveness of different strategies. Studies about awareness, not with engineering students, came to different conclusions. While Karpicke, Butler, and Roediger III (2009) suggested students are not metacognitively aware of the testing effect, Van Etten et al. (1997) instead made several conclusions speaking in favour of students' metacognitive awareness of the benefits of certain strategies. For example, students used strategies to avoid over- and understudying. This emphasises the need for more research on students' awareness of the effectiveness of their strategies.

One of the more interesting of the aforementioned studies, Karpicke et al. (2009), investigated undergraduate students learning strategies, focusing on what strategies the students used when studying for exams, if they used testing as a strategy, and if they would choose testing or rereading when given only those options. The study was based on previous findings about the testing effect, which refers to the positive effect testing has on long term retention compared to spending the same amount of time repeatedly studying (Karpicke et al., 2009). Testing has been shown to improve the long-term retention of the material even if no feedback is given on the correctness of the response (Roediger and Karpicke, 2006). However, previous research suggests students are not aware of the effect of testing, but instead often reported re-reading as a learning strategy, which has been shown not so effective (Karpicke et al., 2009).

Karpicke et al. (2009) focused on mainly two learning strategies while there is now evidence for the effectiveness, or in some cases lack of effectiveness, of several other strategies (Dunlosky et al., 2013). Another aspect of students' learning strategies not captured by Karpicke et al. (2009) is what motivates the students' choice of strategies. In addition, the context of Karpicke et. al.'s (2009) study was somewhat unclear, not describing the course or the program in which the students were enrolled. The findings of this study are interesting but there is a need to investigate the use of a greater variety of strategies in different contexts, especially in an engineering education setting.

This thesis therefore aims to expand Karpicke et. al.'s (2009) study to an engineering education setting, with students at different engineering programs studying for written exams in different types of courses. The contribution is however not only to expand Karpicke et. al.'s (2009) study into engineering education, but also to take into account that both what programs students are studying and which courses they are currently enrolled in might affect their use of different strategies. This hypothesis is in line with previous research that students adapt their strategies depending on the learning situation (Schmeck & Geisler-Brenstein, 1989).

This thesis contributes to existing research on learning strategies by investigating students' motivation for choosing certain strategies and their awareness of the effectiveness of some of their strategies. In addition, the questionnaire developed as part of the study is a contribution in itself, as it constitutes a theory- and research-based tool which, as opposed to many previous tools (see for example Hadwin et al., 2001), takes context (both type of course and program) into account. As students are also asked why they use their strategies and to rate the effectiveness of some of their strategies, the survey makes it possible to dig deeper into students' learning strategies outside class and the presumably sometimes complex reasons for their choices. In conclusion, this study increases our understanding of engineering students' learning strategies and thereby provides important knowledge both for teachers to regulate their teaching and for researchers to design effective interventions. The questionnaire in itself also serves as a robust instrument that can be used by others, researchers as well as teachers in engineering and other higher education, to further increase this understanding and thereby provide an even better base for improving teaching to better support students learning and for designing effective interventions.

The remaining parts of the thesis are structured as follows: The introduction will continue by stating the aim, research questions, scope and delimitations of this thesis. After this introduction, the next section 2 Overview of theory and previous research, will provide a theoretical background and overview of previous research. Thereafter, our method will be described in section 3, Method, and our findings reported in section 4 Results. Lastly, the findings will be discussed in section 5 Discussion, before drawing conclusions in sub-section 5.5 Conclusion, to provide answers to the research questions. The conclusion (section 5.5 Conclusion) also includes some further implications, an explanation of what the contribution of this thesis is and some suggestions for future research.

1.1 Aim & Research questions

This thesis aims to partially replicate and expand the article *"Metacognitive strategies in student learning: Do students practise retrieval when they study on their own?"* by Karpicke et al. (2009) by mapping what strategies engineering students use in a real-world setting, investigate the students' motivation for choosing certain strategies, and probe their awareness of the effectiveness of some of their strategies. The thesis also aims to compare these factors across two different engineering programs and investigate if differences can be seen between courses focusing on calculations and courses focusing on concepts (in other words on learning facts and reason based on those facts). The following research questions are therefore addressed in this study:

RQ1: What is the distribution of reported learning strategies across engineering programs and types of courses?
RQ2: What motivates the students' choice of strategies?
RQ3: How aware are the students of the effectiveness of their strategies?

1.2 Scope and delimitations

In total, we studied the learning strategies of students in four different courses, two at bioengineering and two at civil engineering at Chalmers University of Technology. Two of the courses, one at each program, were mathematical courses with a lot of calculations. The other two courses were specific for bioengineering and civil engineering respectively and consisted of learning facts and reasoning based on those facts rather than doing calculations. This type of course may also be called conceptual. No courses that were a mix of the two types, with both much facts to learn and much focus on calculations, were studied.

The mathematical courses chosen were mandatory courses in the first year at each program and the conceptual courses mandatory courses in the second year. This study did however not focus on differences in learning strategies based on if the students studied their first or second year. Students from both the first and second year were studied, but this was based on when courses of the selected types were given.

Data was only gathered through a questionnaire, with both open and forced report question, and through a focus group that aimed to improve the design of the questionnaire. When the design was completed, data was only gathered through the questionnaire. No other methods, such as interviews or focus groups, were used. This choice is motivated further in section 3, Method.

Mostly students at bioengineering and civil engineering were studied, and only those students were included in the comparisons across programs and types of courses. These programs are quite different, with different focuses, which was partly why they were chosen. They were also chosen because we have ourselves studied civil and bioengineering respectively, which was beneficial for example when choosing appropriate courses to include. One possibility would have been to study several programs and not only these two, but this was disregarded to make the project workload suitable for a master's thesis. However, students from other programs that were enrolled in the selected courses and thereby present when the survey was conducted were included in the part of the study where no comparisons based on context was done. In the courses belonging to civil engineering, data from students in three other programs that participated in the same courses was included. Those programs were civil engineering, architecture in combination with civil engineering and the program for business and entrepreneurship.

The participating students had, presumably, different backgrounds in a number of ways. For example, age, gender, cultural background, if they had studied at university before and if so for how long may have differed. This master's thesis did not focus on those factors. However, it is important to notice that other factors than the ones studied may be important to take into account when trying to make conclusions. For example, some unstudied factors may still have affected why students chose to use certain learning strategies. To address a small number of those factors, a few background questions were included in the questionnaire.

Learning strategies may be what student apply both in and outside class. For example, it can be considered a strategy to go to class when lectures are not mandatory. However, this study only includes what students do outside class.

What is defined as an effective learning strategy will be based on previous research. The effectiveness of the students learning strategies will not be cross-checked with their exam results.

2 Overview of theory and previous research

This chapter presents an introduction to self-regulated learning, which in short refers to a process where students regulate their learning and use various learning strategies as part of this process (Pintrich, 2000). The reader is also presented with an overview of different learning strategies based on previous research and an overview of previous research on what learning strategies students use.

2.1 Self-regulated learning and metacognition

Self-regulated learning (SRL) constitutes an important part of effective learning, as students who are good at reflecting upon their own learning do learn better (Winne & Hadwin, 2008). Pintrich (2000) explained self-regulated learning as:

> "… an active constructive process whereby students set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour guided and constrained by their goals and the contextual features of the environment." (Pintrich, 2000, p. 453)

It can also be described as a cyclical process consisting of three phases; the forethought phase, the performance phase and the self-reflection phase (Zimmerman, 2008). The forethought phase involves task analysis, for example goal setting and planning, and self-efficacy beliefs. The performance phase involves self-control, for example self-instruction, attention focusing and task strategies, and self-observation such as metacognitive monitoring. Finally, the self-reflection phase involves self-judgement and self-reaction, for example self-satisfaction or self-affect. However, it is important to note that not all learning is classified as SRL and that students might not self-regulate all their learning experiences, even though it constitutes an important part of effective learning. There are several theories on why students do not do this, including that SRL-strategies often require additional preparation time, vigilance and effort (Zimmerman, 2008).

As suggested above, research and theories on SRL overlap with metacognitive research (Tanner, 2012). Metacognition can be described as a people's cognition about their own cognitions, in other words how people think about their own thinking (Nelson, 2002). Expansions on this definition include planning, monitoring and evaluating one's own learning process (Tanner, 2012). This overlaps with the descriptions of SRL above, even though SRL also involves self-regulation of motivation, behaviour and agency on context (Pintrich, 2000). However, students' perceived metacognitive knowledge might sometimes be incorrect. Metacognitive illusions often lead to students misjudging their learning (Serra & Metcalfe, 2009). These illusions are based on how familiar students are with the topic and how hard, or easy, they think it is (Serra & Metcalfe, 2009). In addition to being inaccurate in judging their own learning, many students do not understand how learning occurs or what learning strategies are effective (Karpicke et al., 2009).

According to Flavell (1979), strategies can be aimed at either cognitive or metacognitive goals. He stated that:

> "cognitive strategies are invoked to make cognitive progress, metacognitive strategies to monitor it" (Flavell, 1979, p. 909)

An example of a metacognitive goal is assessing your knowledge, which makes "testing what you know" a metacognitive strategy. If you instead choose to reread your notes or the textbook, you use a cognitive strategy aimed at the cognitive goal of increasing your knowledge. However, there is not always a clear distinction between cognitive and metacognitive strategies, and they may overlap. The same strategy might be used in order to achieve a cognitive or metacognitive goal or both types of goals. It may also be a metacognitive strategy even though the student thinks of it as a cognitive strategy. Flavell (1979) exemplified this by stating that a student may test his/her knowledge to improve the knowledge itself, but at the same time monitors the knowledge, even though that was not the student's motivation for testing, and therefore unconsciously uses it as a metacognitive strategy.

Several studies have investigated the important role of metacognition when students engage in problem-solving and knowledge transfer activities (Grohs et al., 2018). For example, high preforming students in a statistical course engaged in the metacognitive strategy of self-explanation to a significantly higher extent than the low preforming students (Litzinger et al., 2010). A similar relationship between the use of metacognitive abilities and performance has been shown in courses of civil engineering (Meyer, Knight, Callaghan, & Baldock, 2015) and chemical engineering (Ko & Hayes, 1994).

For engineering students specifically, five benefits of applying metacognitive activities have been shown (Meyer et al., 2015); (1) it helps them in understanding how to associate different knowledge to each other and create connections between them, (2) aids in long-term understanding of concepts, (3) promotes self-confidence, (4) increases awareness and aids in identifying knowledge gaps and (5) provides an opportunity for teachers to aid the students understanding of the activity by giving feedback on a corresponding metacognitive level. In other words, the use of metacognitive strategies is highly beneficial for engineering students' learning.

It has also been shown that students, although not specifically engineering students, adapt what strategies they use to the cognitive level of the exam; more specifically based on whether the exam tests surface or deep learning (Abd-El-Fattah, 2011). Both deep and surface learning consist mostly of cognitive processes, but the former consists of metacognitive processes to a higher extent than the later (Biggs, 1988). Abd-El-Fattah (2011) not only showed that students chose strategies that matched the cognitive processing demands of the exam, but also that they performed better because of this adaptation. In addition, students performed better if their preparation matched the type of exam.

In conclusion, self-regulated learning and the use of metacognitive strategies should be beneficial for students learning in general and engineering students learning in particular. It is thus both interesting and relevant to investigate whether engineering students use metacognitive strategies, and to what extent they self-regulate their learning. Since using metacognitive strategies, and thereby SRL-strategies, could be done consciously or unconsciously, as suggested by Flavell (1979), it is also crucial to find out how students reflect upon of why they study as they do, and how metacognitively aware they are of the effectiveness of their learning strategies.

2.2 Overview of research on utility and effectiveness of various learning strategies

A framework for how effective various learning strategies are is needed to be able to evaluate the students' awareness of the effectiveness of their strategies. In a meta-analysis of available research, Dunlosky et al. (2013) evaluated the relative utility of ten different learning strategies and their generalisability across learning conditions, student characteristics, materials and criterion task. They included re-reading and practice testing, the strategies in focus in the study conducted by Karpicke et al. (2009), as well as elaborative interrogation, self-explanation, summarisation, highlighting (or underlining), keyword mnemonic, imagery use for text learning, distributed practice (spacing) and interleaved practice (Dunlosky et al., 2013). Variations in both generalisability and effectiveness were seen, and the strategies were rated as having generally high, moderate or low utility. The evaluation was based on existing research and, in some cases, the need for further research to clarify the effectiveness of certain strategies across different learning conditions, student characteristics, materials and criterion task. The ratings and summarised motivations for the ratings can be seen in Table 1.

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Table 1: Dunlosky et al.'s (2013) rating of the effectiveness of ten learning strategies, including motivations for the ratings.

Strategy	Effectiveness	Comment
Practice testing	High	Refers to testing as a learning activity and not as part of a course. The beneficial effects on learning, retention and comprehension are relatively well studied, also for undergraduates. Can mean testing to benefit from the testing effect (less effective) or testing for feedback (more effective as it also provides information on what to focus further studying on). It is beneficial for students of different knowledge levels and on actual summative course assessments. It takes a modest amount of time and requires minimal training. Further, it outperforms unguided restudy.
Distributed practice (spacing)	High	Refers to when students spread out their studying over time instead of massing it. Does not include what students do during sessions. The distribution can be within single study sessions or across sessions; research has shown benefits for both. A shortage is the phenomenon procrastination scallop, which refers to the typical study pattern where the time students spend studying increases as the exam gets closer (Michael, 1991). Theories suggest that the benefit depends upon that the studied material is not fresh in the student's memory in the same way as when massing learning opportunities. This also lowers the risk of metacognitive illusions based on familiarity (see Serra and Metcalfe, 2009, on metacognitive illusions). Effective for undergraduates and for many different materials and domains, including biology and mathematics. More research on complex material is needed.
Elaborative interrogation	Moderate	Means generating an explanation for why a stated fact or concept is true. Effective for various factual topics and materials, for example for undergraduates in a biology course, as shown by (Smith, Holliday, & Austin, 2010). Supports integration of new knowledge with prior knowledge. The effect increases with increased prior knowledge. Uncertain benefits for those with low level of prior knowledge (Dunlosky et al., 2013).
Self-explanation	Moderate	Means explaining to oneself how new information is related to old information or explain steps taken when solving a problem or a task. Has been explored for college students over a wide range of materials, including solving various math problem and learning from texts. The effect decreases if the student has access to explanations. Works with little or no practice, but the effect increases with the quality of the student's explanations. The results are promising but more research is needed on several aspects.
Interleaved practice	Moderate	Refers to when students alternate practice of different kind of items or problems. Relatively unstudied. Most research has been done on college students. Results across materials are mixed, but promising for several math skills, including algebraic skills. It might help students discriminate between different kinds of problems and solution methods by both making comparison of tasks easier and make the practice of problems of the same kind distributed over time. Students need to practice enough, or get enough instructions, on an individual task before starting to alternate between them to benefit from interleaved practice. Great need for more research.

Summarisation	Low	More effective than just reading. Can mean many different things, ranging from practicing recall to copying parts of texts, which makes it hard to draw conclusions on its effectiveness. According to A. L. Brown, Campione, and Day (1981), a good summary excludes unimportant or repetitive material, identifies the main points and successfully captures the gist of the text. The synthesizing, as opposed to copying parts of a text, is an important part of a successful summary. More research is needed across different levels of Bloom's taxonomy (for more information on Bloom's taxonomy, see Krathwohl, 2002). Summarising might deserve a higher rating for undergraduates, if the students are good at summarising and find it easy to use.
Imagery for text	Low	Means creating mental images for content of text. Can involve using prior knowledge when creating the image and may be helpful for mental organisation or integration of information from the text. There are many uncertainties and mixed results regarding the effectiveness of this strategy. Some studies have shown a positive effect while some have not. What material imagery for text has an effect for is also unclear. As with many other strategies, the longevity is quite unstudied. However, there is some relatively new research that is promising for the potential utility of the strategy. It is more broadly applicable than keyword mnemonic but have not been studied for undergraduates to the same extent.
Rereading	Low	Frequently used by students. Has been studied for undergraduates for texts of various lengths and for various materials, including physics and biology. Has been shown to have some effect on free recall. Research on the effect on comprehension has shown inconsistent results, as has the few studies studying the effect in a real world setting with course content and course related tests. It is easy to use and needs no training, but many other strategies have been shown more effective for promoting learning.
Keyword mnemonic	Low	To identify or come up with keywords which you then visualise by creating mental images. One example of the strategy is if you try to learn the French word la dent (the tooth) and use the English word dentist as a keyword, which you visualise as a dentist holding a huge tooth. One of the most well studied strategies, also for college students. It has been shown to enhance both learning and comprehension for a variety of materials, including learning science terms and medical terminology. Concrete keywords are easier to visualise than abstract. There is a need for more studies both where students have to generate their own keywords and on the durability of the effect.
Highlighting/ underlining	Low	Common strategy for students. Easy to use and adds little time compared to only reading. It is effective to some extent, which may be explained by the isolation effect, meaning that items that stands out are easier to remember. Overmarking, which is common amongst undergraduates, takes away the effect of having to process the information to identify the most important parts. Most studies have shown no benefit for highlighting/underlining over reading, but research in a real-world context is limited.

As can be seen in Table 1, only practice testing and distributed practice were rated as having high effectiveness (Dunlosky et al., 2013). Three strategies, elaborative interrogation, self-explanation and interleaved practice, were rated as moderately effective, while the remaining five strategies were rated as having low effectiveness. However, it is important to note that the strategies may vary in effectiveness depending on materials, subject, the learners themselves and other factors (Dunlosky et al., 2013). For example, summarising got the lowest of the three ratings but Dunlosky et al. (2013) also pointed out that it might deserve a higher rating for undergraduates who are skilled at summarising, and may also be used to practice testing.

2.3 Methods for mapping students' learning strategies

A major challenge in research on learning strategies is the difficulty of obtaining data of what students actually think and do. Some researchers have used a software to trace what students actually do when they study with the help of that same software (see for example Nesbit et al., 2006; Winne & Jamieson-Noel, 2002, 2003), while many use self-report data, relying on the students' perception of their studying (see for example Carrier, 2003; Gurung, 2005; Gurung et al., 2010; Hadwin et al., 2001; Van Etten et al., 1997). Self-report data can be gathered by interviews, focus-groups or, perhaps more efficiently, questionnaires (Esaiasson, Gilljam, Oscarsson, & Wängnerud, 2007). Many studies have been based on questionnaires designed for that specific study, but there are some standardised questionnaires related to learning strategies, including the Learning and Study Strategies Inventory (LASSI; Weinstein, Zimmermann, & Palmer, 1988) and the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, 1991). These two questionnaires are presented briefly below. In addition, some criticism against them is summarised and some general issues with self-report data on learning strategies presented.

The LASSI consists of 77 questions and aims to measure the students' strategies for learning in the form of thoughts and behaviour (Weinstein, 1994). It addresses covert and overt behaviours relating to learning and studying in general (Hadwin et al., 2001; Weinstein et al., 1988). According to Cano (2006), LASSI is based on two models. The first one is the general model of learning and cognition by Simon (1979), which describes the student as an active, self-determined individual that manufactures knowledge and processes information. The second model is the model of strategic learning by Claire Ellen Weinstein (1994). It too puts the individual in the centre by identifying the student's skill, will and self-regulation as three interactive components important for successful learning.

The Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, 1991) addresses learning strategies and motivational orientation in relation to specific courses and was design to be used at college level. It consists of 81 items, of which 31 items regards students' motivations, 31 items for students' use of cognitive and metacognitive strategies and 19 items for students' use of resources. The motivation section of MSLQ can be divided into 6 categories. These describe both the motivation to why students participate in the course and more task specific motivation within the course, for example the motivation to how they prepare for an exam.

Hadwin et al. (2001) criticised both LASSI and MSLQ for not taking context into account in a good enough way, pointing out that none of the questionnaires asses if and how students adapt across contexts. In addition, one strategy (for example summarising) might be used either to learn and integrate knowledge or to for example practice testing. These nuances are not captured by the questionnaires. Gurung et al. (2010) also criticised LASSI and similar questionnaires, meaning they are too long and general and do not provide guidance on how to advise students to study.

However, it is also impossible to be sure whether students' self-report data is actually correct, regardless what questionnaire is used. Some research has therefore used a software to trace what students do (for example Nesbit et al., 2006; Winne and Jamieson-Noel, 2002, 2003). The results have conclusively suggested differences between what students self-reported that they did and what the software traced (Winne & Jamieson-Noel, 2002, 2003). However, Nesbit et al. (2006) found that using a software to trace what students do in a real-world setting is not easy, as the students may choose not to use the software but instead completely or partly use strategies not registered by it (for example summarising on paper) or be logged in but do something else completely. The software also only contained the possibility to use and trace a limited number of strategies. Another problem with using this type of software can, according to Nesbit et al. (2006), be that students know they are observed and because of this change their behaviour. Some of these problems are specific for traces, while some also adopts to other methods, like questionnaires (Gurung et al., 2010), in real-world settings. In conclusion, there is currently no perfect method for finding out what learning strategies students use in a real-world setting and why, and there is a need to be careful when interpreting self-report data as well as traces.

2.4 Overview of previous research on learning strategies

In this section, previous research on students' use of learning strategies in a real-world setting is summarised. All included studies investigated learning strategies of students in higher education. What learning strategies engineering students use in STEM-courses seem to be relatively unstudied. Therefore, this chapter includes previous research on engineering students learning strategies in other types of courses as well as research on learning strategies of other students in higher education. Hadwin et al. (2001) pointed out that investigations of which learning strategies students actually use and why they chose those strategies should be done in different contexts, as context might affect the students' decisions. For example, Hadwin et al. (2001) showed that different forms of examinations within a course in educational psychology affected how frequently the students used different learning strategies, selected different study-related resources and adopted goals. This supported Hadwin et al.'s (2001) assumption about students' perception of making different decisions in different study contexts and was also in line with models of self-regulated learning. Different forms of exams are only one example of how context may differ; different courses or different subjects are two other contextual factors that may vary. However, there is little previous research on engineering students learning strategies. Some factors may be similar in other contexts, which means also studies on undergraduates studying non-engineering courses are of interest.

Some research has been done on engineering students learning strategies in language learning (Afshar et al., 2014), in other words with the students we are interested in but in the wrong type of course. Even though some of the strategies used by students have been very specific for language learning (Afshar et al., 2014; Granescu & Literat, 2013), guessing what a word meant based on background knowledge was for example the most frequently used in one study (Granescu & Literat, 2013), some results are still interesting as the students might use similar strategies or show metacognitive awareness to a similar extent in their STEM-courses. For instance, one study found that 20 percent of students used self-evaluation of some sort (Granescu & Literat, 2013). However, these studies used MSLQ to gather data, which as described above has some shortcomings.

Another interesting set of studies are those that have investigated courses where students learn various facts and then reason based on these facts, as some STEM-courses, for example biology courses, may be of this type. Many of these studies have used questionnaires designed specifically for one study, or sometimes gathered data by interviewing students individually or in focus groups. In psychology courses, which may be considered courses of this type, some strategies were common in several studies. Carrier (2003) found that reviewing lecture notes, rereading, highlighting and making chapter notes were used by over half of the students. Similarly, Gurung (2005), who not only investigated what strategies students used but also the time spent on each strategy, found that reading notes or text was reported to be used the most often. Testing knowledge was on the other hand reported as one of the least used (Gurung, 2005). Finally, Gurung et al. (2010), who also investigated students learning strategies in a psychology course, made an interesting remark that it is possible that the reason why their participants used only basic study strategies, such as studying practice exams, was that the exam itself consisted of multiple-choice questions and the course wasn't very advanced. The students therefore did not need any more advanced strategies to succeed. This is in line with research on students' adaptation of their strategies to the cognitive processing demands of the exam (Abd-El-Fattah, 2011).

The study that inspired our study, Karpicke et al. (2009), focused mainly on the strategies rereading and testing, and students' metacognitive awareness of the testing effect. When investigating undergraduates use of learning strategies when preparing for an exam, Karpicke et al. (2009) found that as many as 83.6 percent of the students listed rereading textbook or notes as one of their strategies, while 54.8 listed it as the strategy they used the most often. This made it the most popular of all strategies the students listed and is also similar to what Carrier (2003) and Gurung (2005) found. Further, some of the students got to choose between rereading and testing their knowledge without the possibility to restudy afterwards, while some got to choose between rereading and testing their knowledge with the possibility to restudy. Out of the first group, only 17.8 percent of the student chose the option to test without restudying, while 57.4 percent chose rereading parts of the text or the entire text. When the testing option included the possibility to restudy 42.1 percent chose testing and 40.8 percent restudying. Based on these results, Karpicke et. al. (2009) suggested students lack metacognitive awareness of the testing effect. They also suggested this has consequences for students' real-world study behaviours. Based on the results in Karpicke et. al. (2009), students seem to think testing for feedback is better than just testing, which has been shown to be correct (Dunlosky et. al., 2013). This could be interpreted in favour of the students' metacognitive awareness when choosing strategies, even if they are not metacognitively aware of the testing effect.

In contrast to Karpicke et al.'s (2009) suggestions, Van Etten et al. (1997) concluded that students are sometimes aware of the benefits of certain strategies, like distributed practice instead of massing study sessions and procrastinating their studying to the last week, but still do not always use that knowledge. Their study focused on mapping what strategies undergraduates used as well as trying to draw conclusions about how aware students are of the benefits of certain strategies. They stated that there are many complex factors that could influence students' preparation for exams (Van Etten et al., 1997). As opposed to Karpicke et al. (2009), Van Etten et al. (1997) made several conclusions in favour of students' metacognitive awareness of the benefits of certain strategies. For example, students perceived studying in a group beneficial to avoid missing important information, find and sort out misconceptions and to get feedback about test readiness, which could help them avoid over- or understudying. Students also mentioned spacing as part of an effective preparation for an exam (Van Etten et al., 1997), which indeed shows some awareness. Further, memorising, highlighting, rewriting and similar strategies were used by over 90 percent of the students, while strategies focusing on more transformative processing, like reorganising, making acronyms and imagery, were each used by about 30 percent of the students. However, some strategies in this study were still somewhat ambiguous as to what they actually meant, as the strategy study old exams, despite a very ambitious method with several rounds of focus groups before finally designing a questionnaire. Van Etten et al. (1997) did also not take the participants academic major or what course they were enrolled in into account, which is interesting as they themselves stated that many complex factors could influence what students do and that it is important to take that into account.

Regarding academic achievement and the use of various learning strategies, some research has been conducted in higher education although not specifically in engineering education (see for example Seabi, 2011; Yip, 2007), including more detailed descriptions of what strategies students used. For example, (Hartwig & Dunlosky, 2012) found a positive association between psychology students' use of both self-testing and rereading and achievement in the form of GDP (grade point average). Students' choice of strategies was however not a strong predictor of achievement, despite the fact that some strategies have been shown to be more effective. Hartwig and Dunlosky (2012) argued that it is possible that high achieving students achieve their success in spite of using the same strategies as low performers due to a more adaptive use of those strategies. Their success may be connected to other factors rather than the use of effective strategies. Such factors could be prior experience, intelligence or degree of motivation.

Further, Hartwig and Dunlosky (2012) focused especially on rereading and practice testing, similarly to Karpicke. Hartwig et al.'s (2012) study was an expansion of Kornell and Bjork (2007). The results of both studies are interesting to compare with how engineering students' study in the absence of previous research on engineering students. Kornell and Bjork (2007) concluded that students make choices in accordance with how highly prioritised the information is in the course rather than to try maximising long-term learning. Some of the learning strategies reported in the study by Hartwig and Dunlosky (2012) can be seen in Table 2.

Table 2: Students' reported use of learning strategies in the study by Hartwig and Dunlosky (2012)

Strategy	Percentage of students who reported they used the strategy
Test yourself with questions or practice problems	71
Use flashcards	62
Recopy your notes	33
Reread chapters, articles, notes, etc.	66
Make outlines	22
Underline or highlight while reading	72
Make diagrams, charts, or pictures	15
Study with friends N/A	50
"Cram" lots of information the night before the test	66
Ask questions or verbally participate during class	37
Other (Please describe:__________)	6

As shown in Table 2, practice testing was the most common strategy. Note that the questions were forced report questions and the strategies were already listed in the questionnaire. This might explain why so many students listed practice testing compared to the study by Gurung (2005), where it was one of the least used strategy.

Some results from both Hartwig and Dunlosky (2012) and Kornell and Bjork (2007) about students' use of rereading and their motivation for quizzing themselves are shown in Table 3.

Table 3: Survey results from Kornell and Bjork (2007) and Hartwig and Dunlosky (2012)

Questions	Choices	Percentage of students who agreed to the statement	
		Kornell and Bjork, 2007	Hartwig and Dunlosky, 2012
When you study, do you typically read a textbook/article/other source material more than once?	Yes, I reread whole chapters/articles	16	19
	Yes, I reread sections that I underlined/ highlighted/marked	60	64
	Not usually	23	17
If you quiz yourself while you study (either using a quiz at the end of a chapter, or a practice quiz, or flashcards, or something else), why do you do so?	I learn more that way than I would through rereading	18	27
	To figure out how well I have learned the information I'm studying	68	54
	I find quizzing more enjoyable than reading	4	10
	I usually do not quiz myself	9	9

As can be seen in Table 3, these studies focused very much on if and why students quiz themselves. Still, the motivations have some ambiguity to them and only 9 percent of the students in each study said they did not quiz themselves. The second motivation, "to figure out how well I have learned the information I'm studying", could possibly be interpreted as *practice testing*. On the contrary, Wissman et al. (2012) found that about 60 percent of the students motivated their use of flashcards saying that it helps in memorising and about 30 percent in a way that pointed out that it is easy to use. None of these motivations explicitly stated that students practice testing and this is therefore not in line with the results from Kornell and Bjork (2007) and Hartwig and Dunlosky (2012). This emphasises the need to be careful when interpreting what students actually do, and not only ask what they do but also why and how. It also points out that there is an ambiguity to previous research when these issues have not been investigated further.

A related example of the importance of being careful when interpreting this kind of self-reported data is that Gurung et al. (2010) listed study practice exams as a metacognitive strategy, even though it was not clear what the students actually did when using that strategy as Gurung et al. (2010) did not investigate this. However, using practice exams to study was positively correlated with students' exam scores, which suggests it was effective to some extent (Gurung et al., 2010). This conclusion about using practice exams being a metacognitive strategy and the aforementioned ambiguity as to how quizzing and flashcards were used further highlights the importance of investigating more thoroughly what students do, as one strategy might be used in many different ways and for different purposes. In addition, it is important not to draw conclusions on students' use of a strategy, for example flashcards, and their awareness of its effectiveness without knowing for sure how or why the students use the strategy, especially when only using forced report questions. Students may well be aware of a strategy's effectiveness or lack of effectiveness for different purposes, regardless of whether they use it or not or how they use it. For example, Van Etten et al. (1997) found that many students seemed to be aware that using flashcards to drill important information as a rote strategy for memorising information (which is probably not using it to test oneself) does not help much in understanding the material.

This ambiguity to what students actually do and why, combined with the overlap and lack of clear distinction between metacognitive and cognitive strategies (see Flavell (1979)) might explain why previous research has classified strategies in slightly different ways and into different categories. For example, one study specified rehearsal, organization of ideas, elaboration of ideas and critical thinking categorised as cognitive strategies; metacognition as a metacognitive strategy and time and study environment management, effort regulation, peer learning and help seeking as resource management strategies (Afshar et al., 2014). Another study divided the strategies into cognitive, metacognitive and affective strategies (Granescu & Literat, 2013). Gurung et al. (2010) instead specified the different types a bit more and labelled them as organizational behaviours (for example writing down important dates and applying a study schedule), application behaviours (for example creating questions about the content), elaboration behaviours (for example explaining the content to someone), metacognitive behaviours (for example studying practice exams) and resource use (for example asking friends for help). Yet another study labelled the strategies as repetition-based (for example flashcards used for repetition and mnemonics), cognitive-based (for example studying in a group), procedural (for example time management and organization) and metacognitive (for example practice testing) (Gurung, 2005). Finally, one study grouped the strategies as text-noting strategies (highlight, outlines, copy keywords), mental-learning strategies (for example imaging, relating to old info and self-testing) and reading strategies (reading at different paces, including skimming and rereading) (Wade, Trathen, & Schraw, 1990). Note that this last study differentiated reading into different strategies (Wade et al., 1990), while other studies have listed reading or sometimes rereading as a strategy without further differentiation (see for example Karpicke et al. (2009), Hartwig and Dunlosky (2012) and Gurung (2005)). Interestingly, none of the above studies specified any other strategies than practice testing as metacognitive strategies. This can be questioned drawing on Flavell's (1979) statement that there is not always a clear distinction between cognitive and metacognitive strategies, and that there may be an overlap. Without knowing if students use the strategy to achieve a cognitive or metacognitive goal or both types of goals, it is hard to draw conclusions on what kind of strategy it is used as.

Other interesting findings in two studies using traces were that students did not use some strategies the authors describe as powerful (Winne & Jamieson-Noel, 2002) and assigned less utility to the strategies than the researchers' model did (Winne & Jamieson-Noel, 2003). Winne and Jamieson-Noel (2002) hypothesised that students did not use the powerful strategies due to lack of skills or knowledge about when and how to use them, and possibly also because they are bad at approximating how much time they spend on different strategies, so that they overestimate their effort. When the result then does not turn out as good as they desired, they won't spend time on that seemingly unproductive cognitive activity. However, this does not mean students are not metacognitively aware at all. Students can be metacognitively aware in the sense that they regulate their learning to maximize the outcome, but do so based on misconceptions on what they have actually done. In other worlds they self-regulate ineffectively.

Finally, some research has been investigating engineering students learning strategies in specific STEM-courses, but with slightly different focuses than mapping strategies and trying to draw conclusions about the students' awareness. For example, Lawanto and Santoso (2012) tried to evaluate metacognitive SRL-strategies of engineering students enrolled in an electric circuit course, but focusing on possible differences between the beginning and end of the semester. Another study instead focused on strategies and achievement only, without involving SRL or metacognitive aspects (Grohs et al., 2018). They found that what strategies students used correlated with their performance on an exam in a statistical course in mechanical engineering, while the total time spent preparing for the exam did not correlate with performance. In addition, students who mainly solved problems by themselves performed better than students who mainly solved problems together with peers (Grohs et al., 2018). However, we did not find any research in an engineering education setting similar to Karpicke et al. (2009) or Van Etten et al. (1997), both mapping strategies and trying to draw conclusions about students' metacognitive awareness of the effectiveness of various learning strategies.

To conclude this chapter, there is some ambiguity in previous research regarding what students actually do and why. Moreover, not much research has been conducted in a real-world engineering education setting and the few studies that have been have had slightly different foci. As Winne and Jamieson-Noel (2003) suggested, more research is also needed on how students study and what they understand about how their choices of strategies are linked to achievement, in other words the effectiveness of the strategies.

3 Method

In this section, we will describe our method, starting with the setting and participants before describing the data collection and finally account for how the data was analysed.

3.1 Setting and participants

The participants were 416 engineering students at Chalmers University of Technology in Gothenburg, Sweden, from two different programs: bioengineering and civil engineering. However, some students from other programs were also included, as they were enrolled in the same courses as the civil engineering students and thereby present when the survey was conducted. In total, students enrolled in four different courses were included. Two of those were conceptual courses, namely a biology course in the second year of the bioengineering program and an environmental course in the second year of the civil engineering program. The other two courses, which focused on calculations, consisted of a multivariable calculus course in the first year of the bioengineering program and a course in linear algebra in the first year of civil engineering. All included courses were compulsory for the participants' engineering programs. The exams were in all courses but one taking place at the end of the course, which meant most students answered the questionnaire two to three weeks before their exam. In the conceptual course in civil engineering, the students had already had the exam when completing the survey. They were later having an additional examination of another type, which suggests the written exam might have included less material than the exams in the other courses. This could possibly have affected what learning strategies students used. However, this was not possible to avoid with current resources and time constraints.

For this study, a manageable number of participants corresponded to about two courses in two engineering programs, in total four courses. The programs selected should be quite different but include comparable courses. Another factor considered was that our backgrounds, as engineering students at bioengineering and civil engineering respectively, could be utilised to select appropriate courses in those programs.

When the courses were selected, the comparability across programs was the main criterion. While it was not possible to investigate students from different programs in the exact same courses, great caution was put into finding courses of similar types that were studied at the same time in their respective program. Therefore, both calculation courses are part of the first year of the programs and the conceptual courses part of the second year. This was based on the hypothesis that students might change strategies over time as they become more skilled learners.

3.2 Data collection

A questionnaire was designed to collect data about the students' use and assessment of learning strategies. When choosing what method to use, the desired quantity of data was weighted against quality. Large samples of students were needed to make statistical comparisons between the different groups of learners possible. Solely qualitative methods were therefore discarded and a questionnaire was evaluated to be the best approach (Esaiasson et al., 2007). The study by Karpicke et al. (2009) served as a starting point and partly a framework for choosing method. They conducted a survey in which the participants answered one open response question, where the students listed all the strategies they used while studying, and one forced report question, where they had to choose between repeated reading and practice testing. The students also got to motivate their choice on the forced report question.

As a complement to the questionnaire, focus groups or individual interviews could have added a deeper insight into the students reasoning (Esaiasson et al., 2007). However, this was disregarded because it was estimated to take more time than available. Our study still combined quantitative and qualitative data in the survey, by including both open response and force report questions, to acquire deeper insight than possible with a solely quantitative approach (Esaiasson et al., 2007).

3.2.1 Questionnaire design

The study, and thereby the questionnaire, was designed to partly replicate the study by Karpicke et al. (2009) and to expand it into an engineering education setting, while also addressing some issues with the original study. We will therefore begin this section by describing their questionnaire, before moving on to the design of our questionnaire.

Karpicke et al. (2009) investigated what learning strategies students used, students' metacognitive awareness of the benefits of testing over rereading, and in particular if students were aware of the testing effect. The questions Karpicke et al. (2009) asked the students are shown in Figure 1.

K1:
"What kind of strategies do you use when you are studying? List as many strategies as you use and rank-order them from strategies you use most to strategies you use least often." (Karpicke et al., 2009, 474)

K2a, given to about half of the students:
"Imagine you are reading a textbook chapter for an upcoming exam. After you have read the chapter one time, would you rather:
A: Go back and restudy either the entire chapter or certain parts of the chapter.
B: Try to recall material from the chapter (*without the possibility of restudying the material*).
C: Use some other study technique." (Karpicke et al., 2009, p. 475)

K2b, given to the rest of the students:
"Imagine you are reading a textbook chapter for an upcoming exam. After you have read the chapter one time, would you rather:
A: Go back and restudy either the entire chapter or certain parts of the chapter.
B: Try to recall material from the chapter (*with the possibility of restudying afterward*).
C: Use some other study technique." (Karpicke et al., 2009, p. 477)

Figure 1: Karpicke et al.'s (2009) survey design with the difference between K1a and K1b in italics.

As shown in Figure 1, Karpicke et al.'s (2009) questionnaire was given in two different versions to investigate student awareness of the testing effect and not only the effect of testing for feedback. Each of the students only answered one of the versions. In addition to these questions, the students were also asked to give a brief explanation to their answer to K2a or K2b (Karpicke et al., 2009).

Inspired by this questionnaire, we designed a questionnaire to investigate what learning strategies students use, why they use them and how metacognitively aware they are of the effectiveness of different learning strategies. As our purpose was not identical to that of Karpicke et al. (2009), we could not reuse their questionnaire. Our questionnaire was designed during a period of just over a month and several outlines were discarded along the way to achieve a questionnaire that fulfilled all our criteria. It had to make it possible to answer the research questions; it had to be easy to understand for the students and not possible to misinterpret; it had to make it likely that the students answers could be understood and analysed by us, and it had to take no more than 15 minutes to complete to be able to administer the survey during lectures or mandatory occasions in the selected courses. To make sure the students would not be limited by having to use an L2 language (second language), all questions and instructions were in Swedish, the language used at both programs at the bachelor level. An important aspect of the design was also to avoid some of the issues with Karpicke et al.'s (2009) survey.

Karpicke et al. (2009) did themselves point out one issue with their design regarding the first question: "A clear limitation of the free response question is that our procedure did not prompt each student to elaborate on potentially ambiguous answers" (p. 474-475). They argued that in K1, the students' answers can be ambiguous and that it is therefore hard to interpret if the students stated strategies can be categorized as rereading or testing by recall. For example, when students state that they use flash cards as a strategy, it's impossible to know how they implement that tool; do they use flashcards to test themselves by practicing recall or to reread the information without practicing recall?

Regarding K2, K2a focused only on testing without restudying, even though it is even more effective to test for feedback (Dunlosky et al., 2013). Karpicke et al. (2009) also criticised a previous study by Kornell and Bjork (2007) for framing the question in a way that made the students prone to report practice testing more than in their own study. However, if Kornell and Bjork (2007) made the option to test too attractive, Karpicke et al. (2009) instead made it too unattractive. Despite the testing effect, students would probably want to be able to restudy the material if there was something they did not know about on the test. This highlights the importance of the phrasing of the questions to avoid ambiguous results.

To assure all requirements were met, a pilot survey was conducted with five students studying their fourth and fifth year at bioengineering and civil engineering respectively. After completing the pilot survey, the students participated in a focus group to help us identify possible flaws in the questionnaire design (Esaiasson et al., 2007). We had limited experience in designing questionnaires, which made this step in the process very helpful. For example, questions might be misunderstood by the participants, and if so, there was a risk of gathering data that was hard to understand or not useful to answer the research questions (Esaiasson et al., 2007). The questionnaire finally ended up consisting of some background questions, one open response question on learning strategies, Q1a, with an open response follow-up question on motivation, Q1b, and a forced report question, Q2, focusing on how effective students think their strategies are. After the pilot, minor changes were made to Q1b and a clarification was made in Q1a, as the participants in the pilot survey thought our initial phrasings of these questions were ambiguous. Q2 was completely discarded and a new Q2 was designed. Two versions of Q2 were included in the pilot survey. The final version of Q2 was however none of those, as one of the versions did not target the research questions in a satisfying way and the second one was found to be easily misinterpreted.

The final questionnaire also included an introduction to why the survey was conducted and a few forced report background questions. In the introduction, it was described that we aimed to investigate what learning strategies students at Chalmers used, what course the survey regarded, and a brief description on what to expect regarding type of questions and expenditure of time. The students were also asked to read the questions carefully and answer as honestly as possible. Finally, it was made clear that all answers were anonymous and that the students by answering the questionnaire consented to the answers being used for both this thesis and research. The background questions included gender, program, number of years at university and if they had been studying a technical introduction year before their program. The programs listed in the background questions and what course was named in the text were adapted to the different courses. This part was designed to include all general information necessary for the students to complete the survey and to make it possible for us to identify which program the students were enrolled in.

The remaining questions are shown in Figure 2. This example is from the questionnaire given to students in the conceptual course in the bioengineering program.

Question 1a
What strategies do you use when you study for the exam in KMG050 - Cell and molecular biology 2? List all strategies you use and rank-order them from the ones you use the most often to the ones you use the least often.

Question 1b
Motivate for each one of your three most used strategies why you use them?
(If you listed fewer than three strategies, motivate for the ones you listed.)

Question 2
Answer the question by following the two steps below. If you have any comments, there is space to write them at the bottom of the page.
1) Read the strategies carefully and check the ones you use in the course KMG050 - Cell and molecular biology 2.
2) How effective do you think the strategies you checked are to learn what comes on the exam in the course KMG050 - Cell and molecular biology 2? Circle one number for each of the strategies you use.

I use this strategy									
☐	Identify/come up with keywords and create mental images of those to remember/learn the information linked to the keywords	Low effectiveness	1	2	3	4	5	6	High effectiveness
☐	Write summaries	Low effectiveness	1	2	3	4	5	6	High effectiveness
☐	Check what you know of the course content by testing yourself on it	Low effectiveness	1	2	3	4	5	6	High effectiveness
☐	Read course material and/or your own notes more than once	Low effectiveness	1	2	3	4	5	6	High effectiveness
☐	Highlight or underline in books or notes	Low effectiveness	1	2	3	4	5	6	High effectiveness
☐	Try to explain to oneself why facts or concepts are true/correct	Low effectiveness	1	2	3	4	5	6	High effectiveness
☐	Try to explain to oneself how new information is related to old, or explain the different steps taken when solving a problem/a task	Low effectiveness	1	2	3	4	5	6	High effectiveness

Additional comments:

Figure 2: Questionnaire design

As shown in Figure 2, the first part of the first question, Q1a, replicated K1 in Karpicke et al. (2009). Q1a was, as well as the rest of the survey, adapted for each course by including the name of the course. In a follow-up question to Q1a, called Q1b, students were asked to motivate why they used their three most used strategies or motivate for all they listed if they listed fewer than three. The last question, Q2, aimed to investigate how aware the students were of the effectiveness of their strategies. They were asked to rank the effectiveness of seven learning strategies. The learning strategies were chosen from Dunlosky et al. (2013), which will be described later in this section. Finally, the questionnaire included the opportunity for the students to write a comment if they wanted to. The questionnaire was in Swedish but is presented in English in this report. It can also be seen in Swedish in Attachment A since it is hard to capture the small nuances in the English translations.

The design was somewhat similar to Karpicke et al. (2009), but also quite different. This is summarised in Table 4.

Table 4: Comparison of our study to Karpicke et al.'s (2009) study.

	Karpicke et al. (2009)	Current study
Purpose	Map what learning strategies students use and investigate their metacognitive awareness of the testing effect.	Map what learning strategies students use and why and compare this across context. Investigate their metacognitive awareness of seven different learning strategies.
Students	Undergraduates, unspecified major.	Engineering students (undergraduates) from two different programs.
Learning content	Unspecified, preparing for exams.	Calculation and conceptual courses that were part of their programs, preparing for written exams.
Our RQ1: What is the distribution of reported learning strategies across engineering programs and types of courses?	Students were asked to list strategies in question K1. No comparison was made across context.	Students were asked to list strategies in question Q1a. The results were compared across programs and types of courses.
Our RQ2: What motivates the students' choice of strategies?	Not considered.	Students were asked to motivate their three most used strategies in question Q1b.
Our RQ3: How aware are the students of the effectiveness of their strategies?	Students were asked to choose between rereading and practicing recall (with or without the possibility to restudy) in question K2a or K2b. Students were asked to motivate their choice.	Students were asked to rate the effectiveness of up to seven strategies chosen from Dunlosky et al. (2013), but only the strategies they used in their course, in question Q2. No motivation was included, except for the possibility to write a comment. However, students' reflections upon the effectiveness of their strategies was also addressed by question Q1b.

As shown in Table 4, there are some differences regarding both the actual design and the context. The first question was very similar, but we also asked the students to motivate their choice of strategies. In the second question, Karpicke et al. (2009) focused on two strategies while we included seven strategies. Note that Karpicke et al. (2009) had a different purpose than us, and investigated what learning strategies students used, students' metacognitive awareness of the benefits of testing over rereading, and in particular if students were aware of the testing effect.

Several considerations motivated the design of Q1a and Q1b. As Lawanto and Santoso (2012) stated when criticising their own study, open response questions can be used to obtain more in-depth perspectives than would be obtained with forced-report questions. The open question format gives the student the opportunity to freely answer the question without being limited by the questionnaire and our imagination (Esaiasson et al., 2007). Possible negative aspects of an open questions format are that the answering frequency might be lower than with forced questions due to higher effort in answering, seen that not all students are keen on writing, lowering the representativeness (Esaiasson et al., 2007). This gives arguments for forced report questions if possible. However, due to the character of the research questions, it is hard to formulate forced report questions that measure what is intended without affecting and limiting the students' answers. It would have been hard both to address the issue with ambiguous answers and to answer what motivates students' choice of strategies (RQ2), without an open response follow-up question about why the students use their strategies. In addition, this question could help in answering how aware students are of the effectiveness of their strategies (RQ3). To limit the effort for the students, they were only asked to motivate their three most often used strategies in Q1b.

The last question, Q2, targets how aware the students are of the effectiveness of their strategies (RQ3). It was the one demanding the most cautious design to fulfil its purpose. The two steps of the question were explained carefully and stepwise to make sure the students understood what they were asked to do. To make it possible to compare the results with previous research, seven of the ten learning strategies from Dunlosky et al.'s (2013) meta-analysis of effective learning strategies were included. The included strategies were the ones considered relevant to the type of student group, level of education, literature and research questions. The motivations for including or excluding strategies are shown in Table 5.

Table 5: Included and excluded learning strategies in Q2.

Learning strategy	Included	Motivation for inclusion or exclusion
Keyword mnemonic	Yes	Relevant for university students that participate in a conceptual course, trying to remember facts and new words (Dunlosky et al., 2013).
Summarisation Practice testing Rereading Highlighting	Yes	Strongly connected to Karpicke et al. (2009).
Self-explanation	Yes	Relevant for university students and the learning strategy has broad application within both conceptual and calculation courses (Dunlosky et al., 2013).
Elaborative interrogation	Yes	Relevant for university students, and especially as the strategy has been shown effective for undergraduate biology students (Dunlosky et al., 2013).
Imagery for text	No	Poor connection to university student group and further research is needed in order to conclude when the learning strategy does and does not work (Dunlosky et al., 2013).
Distributed practice Interleaved practice	No	Poor connection to our research questions because our study focuses on what learning strategies students use rather than when or the order they do it.

As shown in Table 5, all strategies except for interleaved practice, distributed practice and imagery for text were included.

To address the question of how metacognitively aware students are of the effectiveness of their strategies (RQ3), the students were asked to rate only the effectiveness of the strategies they used, and thereby should have some thoughts about the effectiveness of. The students rated the effectiveness on a Likert-type scale with six levels, ranging from low effectiveness to high effectiveness. An even number of levels was chosen because it forced the students to make a positive or negative evaluation (Gracyalny, 2017). There was no neutral option or option to say they did not know. When deciding what even number of categories to use, the number of questions (seven) and the possibility to differentiate the effectiveness of different strategies were considered (Jamieson, 2008). In addition, the rating of the effectiveness of different strategies made by Dunlosky et al. (2013) used three categories. As that meta-analysis was to be used as a reference of the effectiveness of different strategies, it was suitable to choose a number evenly divisible by three. Even though the effectiveness is much more complex than a number on a Likert-type scale converted to low, moderate or high effectiveness, it still made the comparison of the students' perceived effectiveness of strategies to the result of the meta-analysis by Dunlosky et al. (2013) easier than if four or eight categories had been used.

3.2.2 Survey execution

The questionnaire was administered on paper on mandatory occasions or lectures which the lecturers thought many students would attend. When collecting data with a questionnaire there are, according to Brown (2001), three components in the execution that need to be addressed: (1) retaining a high response rate; (2) ensuring that the questions are understood by the respondents; (3) knowing and controlling the conditions when the questionnaire is filled out. An online questionnaire is convenient for the researchers in terms of time and data analysis, but the three components according to Brown (2001) is harder to meet because: (1) the response rate is usually low; (2) the questionnaire must be totally self-explanatory; (3) the conditions when the questionnaire is filled out is unknown. An online questionnaire was disregarded, and a group-administered questionnaire was chosen, where the participants were gathered in one location to answer the questionnaire during an event with high or mandatory attendance with time set apart for answering the questionnaire in paper form. This generates more work for the researchers but addresses the components described by Brown (2001) to a higher extent because: (1) the group will have a high attendance due to the chosen event and the participants will to a higher extent feel obligated to answer the survey; (2) when one is present during the survey one gets the chance to clarify questions that are misunderstood by the participants; (3) one knows the conditions as one is present when the questionnaire is filled out. Furthermore, a paper questionnaire facilitated control over that everyone completed the questionnaire and by printing paper and bringing pencils one minimises the chance of technical problems that can occur with a web-based questionnaire.

3.3 Data analysis

After completing the data collection, the answers to the forced report question, Q2, were digitalised and the answers to the open response questions, Q1a and Q1b, were categorised and digitalised. To increase the validity of the results, measurements were taken to attain a good intercoder reliability, in other words minimise the risk that we (the coders) categorised the answers in slightly different ways (Lombard, Snyder-Duch, & Campanella Bracken, 2017). First, we both individually looked at a minimum of 20 answered questionnaires to identify possible categories. Then the categories were discussed and a first set of categories decided on, with the possibility to add more categories later if needed. The first ten answers were categorised by both of us together, to get a common framework for how to interpret the answers and categories. The following ten answers were also categorised by us both, but separately. If the intercoder reliability exceeded 90 percent, which was suggested as an acceptable level by Lombard et al. (2017), each of us categorised half of the remaining answers. To categorise students' answers about motivations for using strategies with an acceptable intercoder reliability, more answers had to be categorised by both coders separately for this question (Q1b). To make sure the consistency in the categorisation was maintained through the categorisation process, about 10 percent of the remaining answers were also categorised by both of us. In addition, both of us were sitting in the same room during all categorisation to be able to discuss how to interpret tricky formulations.

When categorising the strategies and motivations, it was decided that two strategies could get the same placing (for example the one used the most often) and that one strategy could have many motivations, as this turned out to be necessary based on the students' answers.

The categorised answers, as well as the answers to the background questions and forced report question were digitalised into MS Excel. Descriptive statistics of what strategies were the most used ones for all students and for different subgroups, as in different types of courses and by students studying different programs, were performed. The response rate was also calculated and can be found in section 4 Results. Then, the data was exported to IBM SPSS Statistics, where tests were performed to check if what strategies students chose were independent of factors as program, type of course and gender. This was tested by a Chi-square test (Devore, 2012), with a following calculation of Cramér's V to see how strong the association was (McHugh, 2018).

The motivations were related to strategies, as this was what was included in the research questions. Tables were produced to describe what the most common motivations overall were and what the most common motivations for some of the most used strategies were.

Finally, the results for Q2 were summarised by counting the number of students who checked that they used each strategy, describing what the lowest and highest number circled for each strategy was and calculating the mean and standard deviation for each strategy.

3.3.1 Categorisation of strategies

The categories for the students' strategies are described in Table 6.

Table 6: Explanation of students' strategies

Strategies	Explanation of strategy
Study old exams	In some courses the students were provided with old exams from previous years. These old exams were used by the students to study for the real exam. The old exams can provide information about previous structure, type of questions and a timeframe which can give an indication for the real exam.
Read course material/notes	Students that read all types of material in the course. It could be course literature, PowerPoints, student notes or other provided material. This strategy did not include when the student read something more than once.
Do practice problems	Students did practice problems. They were usually provided by the course and could be calculation problems, facts and reasoning problems or other types of problems to solve.
Summarise	Student that extracted the main points from something and then constructed a summary with it.
Search for information through alternative resources	Students that stated they were actively trying to find information from other sources than the ones provided in the course. Examples of alternative sources were articles, YouTube, online lectures, Wikipedia or books not included in the course.
Discuss with others	Student that actively sought out other people to discuss the course content.
Study in a group	Students that studied together without clearly describing something that could be considered another strategy. If they stated that they discussed with other students, it was instead considered to be the strategy *discuss with others*.
Flashcards/quiz	Students that created a cue/question and an explanation for the information they wanted to learn and used them it to study. The questions could also be made by someone else. These questions could be used for quizzing oneself.
Study things one finds hard/don't know	Students that specifically stated that they studied the things they found hard or did not know.
Restudy/repetition	Student that studied the same things more than one time.
Highlighting/ underlining	Students that used techniques to highlight or underline.
Reread	Students that clearly stated they read the same material more than once.
Practice testing	Students that clearly stated they tested their knowledge, without the opportunity to look at the answer or solution during the test.
Interrogate yourself/get interrogated	Students that received questions to answer from oneself or others. This could be a way of testing one's knowledge.

Explain to oneself or others	This strategy was similar to the strategy *self-explanation* with the exception that this strategy included explaining to others as well. S*elf-explanation* is described in Table 1 in section 2.2 Overview of research on utility and effectiveness of various learning strategies.
Keyword	Students that used keywords for learning. It could be that they identify keywords and then used them for organising or to learn information.
Memorise	Students that used techniques for memorising information.
Mnemonic and acronyms	Students that encoded the information into smaller components which was later used as a cue for retrieving the information such as rules for remembering, acronyms and mnemonics.
Find out what one is supposed to know	Students that actively sought out and identified information that they were supposed to know in this course.
Create a good work environment for studying	Students that used methods for creating an environment that enabled studying or made it easier to study. Examples of this included making sure they would not be disturbed or listening to music in order to make it easier to focus.
Mental imagery	Students that used mental pictures to understand, remember or connect information to each other.
Distributed practice	This strategy is described in Table 1 in section 2.2 Overview of research on utility and effectiveness of various learning strategies.
Mind maps	Students that created "maps" with information that was connected to each other, which could help the students understand the relationship between different information.
Write down something already written	Students that wrote down something that was already written before. This could be students copying their own notes or summaries.
Focus on one type of problem at the time	Students that selected one type of problem and only practiced this for a long period of time before moving on to other types of problems. One can also say that this is the opposite of interleaving practice, which is described in Table 1 in section 2.2 Overview of research on utility and effectiveness of various learning strategies.
Do practice problem more than one time	Student that solved the same problems more than one time. For example, did the same practice problems more than once.
Go to schedule course occasions	Students that attended course occasions. For example, attended lectures, labs or another scheduled occasion in the course. This strategy was outside the scope since the focus of our study was learning strategies used outside of class.
Missing strategy	The student's strategy could not be interpreted or was not considered a strategy.

As show in Table 6, 28 strategies were identified when categorising students' answers to Q1a. For the students' response to be assigned a strategy, the student had to clearly state the name of the strategy or describe it in a way that could be clearly interpreted. If the strategy could not be interpreted it was categorised as *missing strategy*.

3.3.2 Categorisation of motivation

In total, 22 categories of motivation were identified. In this section each motivation is presented. First, student examples of motivations are shown in Table 7, see below, and then further descriptions of some motivations are given.

Table 7: Student examples for each category of motivations.

Motivation	Illustrative quote
It is easy (easy to implement, not very demanding)	”Easy way to learn various concepts” “Often feels the easiest to read” “Good … because it goes fast to restudy a lot”
Time efficient	”To study old exams is the most time efficient”
Lack of time/poor planning	”Lack of time” ”I often finishing the assignments and prepare for the exam at the last minute”
Because it’s fun	“A fun way to study theory” “… it becomes more fun”
Easier to focus/spend time on	”I am bad at starting doing things in time at home, there are a lot of things that distracts me. Therefore, easier to promise yourself to go to school” “Then I do not need to carry all my books around and I can study wherever I want”
To learn about the exam	“To see how it is structured, what type of questions will come. To see if some questions are recurring …” “Old exams give me an approximation in how the exam will be”
To identify/test what one knows/comprehends and not	”Good way to test where I am now and compare to the level of difficulty previous years” “To test one’s knowledge and detect what one needs to study more”
To avoiding missing something/to include everything important	”Make sure that one has not missed any topics” “Get knowledge about the things that were not included in the old practice exams”
To identify what one is supposed to know/what is important	”Give a good picture of what I need to know for the exam” “To understand what the examiner puts the most focus on”
It includes the most important/most relevant information	”It includes the most important in the course” “Is often the practice problems that is good to go through before the exams”
To learn it	“Solve practice problems to learn every chapter”
To get an overview	”To get an overview of the course content”
To increase comprehension	“To gain a deeper understanding of concepts / theory” “To get new perspectives or increased understanding” “To create an understanding of how everything is connected”
I learn well/better that way	”I learn best when I get to think about the practice problems” “Good for learning how to solve problems”
It gives good/the best result, it works well/the best	”Because it has worked the best for me”
Good to memorise and/or remember	”Good way to … memorise multiple choice questions that often is recurrent” “To get it stuck in my memory so that it is there for the exam”
To restudy/good repetition	”Good repetition of the things we went through/learned” “Repetition is the mother for success they say”
To practice	”In order to practice questions that might be similar to those we get on the exam”
I learn well by writing	”I learn very well by writing”
It feels good	”It makes me calmer before the exam” “It increases … my self confidence in that I can do it”
Regulate level of difficulty	”The exam questions are more advanced therefore it is better to do this in the end” “Because it is usually best to take practice problems out of the math book, it offers different levels of difficulties”
To increase motivation	”I have poor motivation then I study alone and therefore choose to study with someone”

The students' responses to Q1b were categorised into the motivations shown in Table 7. For a response to be assigned a motivation it had to be clear to us what it meant. We interpreted the motivations with key words together with the meaning of the student's response.

Some motivations need further explanation since some student examples in Table 7 do not describe all aspects of those motivations. The motivation to *learn about the exam*, in addition to the student examples, includes getting information about available time and what information is tested on the exam. There is a difference between *I learn well/better that way* and *to learn it*. In the motivation *I learn well/better that way* the student evaluates the strategy to be good which is not the case in the motivation *to learn it*. Also, there is a difference between *to restudy/good repetition* and *to practice*. To restudy means study something that has already been studied while practice is doing similar types of problems but not the exact same.

Not all motivations could be categorised. This was the case when the motivation was missing, not considered to be a motivation or we could not interpret what the student meant. If so, the motivation was categorised as *motivation missing*.

4 Results

In this section, the results of our study will be presented. First, the response rate and gender distribution will be presented. This is followed by the results connected to each research question. The research questions are restated below.

RQ1: What is the distribution of reported learning strategies across engineering programs and types of courses?
RQ2: What motivates the students' choice of strategies?
RQ3: How aware are the students of the effectiveness of their strategies?

In total, 416 responses were collected. Students from three other programs beside bio- and civil engineering participated, as described in sections 1.2 Scope and delimitations, and 3.1 Setting and participants. The overall response rate was 65.0 percent among all programs that participated in the survey. When comparing the different programs and courses, only bio- and civil engineering students were included. The response rate for these two programs in each course was as follows: bioengineering conceptual 49.3 percent, bioengineering calculation 73.9 percent, civil engineering conceptual 95.4 percent and civil engineering calculation 39.5 percent. The gender distribution was even in civil engineering but uneven in bioengineering, where two-third of the students were females.

4.1 Learning strategies (RQ1)

In this section, the result for RQ1 is presented. RQ1 stated: What is the distribution of reported learning strategies across engineering programs and types of courses?

4.1.1 Distribution of learning strategies for all students

Students listed a wide range of strategies, whereof a small number were more frequently used than the other ones. Among all 416 responses, 28 strategies were identified. The average number of strategies listed was 3.18 with a standard deviation of 0.96. The overall distribution of learning strategies for students in all courses is presented Table 8.

Table 8: The ten most used strategies overall and the students' number one strategy.

Strategy	Percent who list strategy	N	Percent who rank as #1 strategy	n
Study old exams	83.2	(346)	38.5	(160)
Read course material/notes	63.0	(262)	22.1	(92)
Do practice problems	46.6	(194)	20.0	(83)
Summarise	31.3	(130)	11.8	(49)
Search for information through alternative resources	19.5	(81)	1.4	(6)
Discuss with others	17.5	(73)	3.1	(13)
Flashcards/quiz	11.8	(49)	1.4	(6)
Study things one finds hard/don't know	11.1	(46)	1.2	(5)
Restudy/repetition	9.4	(39)	1.0	(4)
Study in a group	8.2	(34)	2.2	(9)

Total number of students in parenthesis.

In Table 8, all strategies listed by more than six percent of the students are included. The most common strategy was to *study old exams,* with 83.2 percent using it and 38.5 percent listing it as their first strategy. To *read course material/notes* was also widely used by the students, with 63.0 percent listing it. Other common learning strategies were to do *practice problem* and *summarise*. The four most used strategies, *study old exams*, *read course material/notes, practice problem* and *summarise*, were also most common as the student's first strategy. In our experience, it is common that the teacher provides problems to solve, pages to read and old exams to practice on. Therefore, it is not surprising that these strategies were common. To conclude, the students used a wide range of strategies. Some strategies were however used more often than others.

Some learning strategies were more common among female than male students. Among all 416 students, there was a significant difference in their choices of strategies when conducting a Chi-square test ($p<0.001$). Also, the Cramer’s V test showed a weak association between strategy and gender ($V=0.216$). For example, female students used *flashcards/quiz* and *discussing with others* about twice as often as male students, and *summarising* about three times as often.

4.1.2 Distribution of learning strategies between programs and type of course

The distribution of learning strategies in each course is presented below in Table 9 to enable a comparison between the programs and different types of courses.

Table 9: Students’ most used strategies (used by at least 20 percent) in different programs and courses

Program and type of course	Strategy	Percent who list strategy		Percent who rank as #1 strategy	
Bioengineering students in calculation course (65)	Do practice problems	83.1	(54)	33.8	(22)
	Study old exams	80.0	(52)	36.9	(24)
	Read course material/notes	58.5	(38)	15.4	(10)
	Search for information through alternative resources	38.5	(25)	4.6	(3)
	Summarise	30.8	(20)	4.6	(3)
Bioengineering students in contextual course (33)	Read course material/notes	90.9	(30)	60.6	(20)
	Study old exams	60.6	(20)	18.2	(6)
	Summarise	57.6	(19)	33.3	(11)
	Discuss in a group	48.5	(16)	6.1	(2)
Civil engineering students in calculation course (51)	Do practice problems	90.2	(46)	52.9	(27)
	Study old exams	86.3	(44)	31.4	(16)
	Read course material/notes	45.1	(23)	9.8	(5)
	Search for information through alternative resources	23.5	(12)	2.0	(1)
Civil engineering students in contextual course (104)	Study old exams	84.6	(88)	46.2	(48)
	Read course material/notes	64.4	(67)	19.2	(20)
	Summarise	43.3	(45)	21.2	(22)
	Flashcards/quiz	27.9	(29)	1.9	(2)

Total number of students in parenthesis.

As shown in Table 9, when comparing programs and type of courses, some similarities and differences emerge about students' choice of learning strategies. The conceptual courses had the same top three strategies, only in different orders. The calculation courses had the same top four strategies in the same order. One strategy common in all courses and programs was to *study old exams* with 60.6 to 86.3 percent. However, it was only the most common one in the conceptual course for civil engineering with 84.6 percent that used it. Another strategy common in all courses and programs was to *read course material/notes,* ranging from 45.1 to 90.9 percent. However, it was more common in the conceptual courses. The most often used strategy in the calculation courses was to do *practice problems,* with as high as 83.1 and 90.2 percent of the students listing it. This can be compared to the conceptual courses, where to *do practice problems* was almost not used at all. The strategy *summarise* was common in conceptual courses with slightly higher usage bioengineering program. To conclude, we could observe a difference in learning strategies between different types of courses, but no major differences between programs. However, there were some minor differences between programs. This could be explained by the fact that the two conceptual courses have more differences between each other and were harder to compare than the calculation courses.

In the conceptual course for civil engineering *flashcards/quizzes* was far more used than in other courses as shown in Table 9. The students' comments in the questionnaire show that there were already existing flashcards on the internet available to everyone in this course, which is shown in comments (1, 2).

(1) *"It was fun and there was already made flashcards that felt summarising"*

(2) *"Found flashcards on the internet"*

This suggests that if *flashcards/quizzes* are more accessible it will be more used by the students.

4.1.3 Significance test between programs and types of courses

The difference in learning strategies were tested between programs and types of courses. Three Chi-square tests for significance and one Cramer's V test for association was done which is shown in Table 10.

Table 10: Test for significance for learning strategies in different types of courses and across programs.

Test for significance between	Chi-square test for significance	Cramer's V test for association
Learning strategies and type of courses	$p<0.001$	$V=0.436$
Learning strategies and calculation courses in each program	$p=0.152$	-
Learning strategies and conceptual courses in each program	$p=0.052$	-

Students learning strategies were compared in different types of courses which is shown in Table 10. A significant difference in what learning strategies students used was found between types of courses ($p<0.001$). The association was found to be moderate

(Cramer's V=0.436). This clearly shows that students used different learning strategies in the calculation courses compared to the conceptual courses in this study.

Students' learning strategies were also compared across programs which is shown in Table 10. The calculation and conceptual courses were then tested separately. The test showed no significant difference in learning strategies when comparing the two calculation courses in each program (p=0.152). The same result was shown when comparing the two conceptual courses in each program (p=0.052). This clearly shows that in this study the students used similar learning strategies for the same type of course regardless of the program.

4.2 Motivation for learning strategies (RQ2)

In this section, the result for RQ2 is presented. RQ2 stated: What motivates the students' choice of strategies?

Students listed many different motivations for their strategies. In total, 22 different kinds of motivations were identified. Also, a single student sometimes listed more than one motivation for a strategy. This suggests that students can have more than one reason for using a strategy. The students' motivations are shown in Table 11.

Table 11: The 12 most listed motivations in all courses

Motivation	Percent who list motivation	
To learn about the exam	55.5	(231)
To increase comprehension	48.1	(200)
It includes the most important/most relevant information	34.9	(145)
To identify what one is supposed to know/what is important	31.0	(129)
I learn good/better that way	30.0	(125)
To restudy/good repetition	30.0	(125)
It gives good/the best result, it works good/the best	26.0	(108)
To get an overview	20.0	(83)
To identify/test what one knows/comprehends and not	19.2	(80)
To learn it	16.1	(67)
To avoiding missing something/to include everything important	12.5	(52)
Good to memorise and/or remember	12.5	(52)

Total number of students in parenthesis.

As shown in Table 11, the students had different motivations for using their learning strategies. The 12 most common motivations for all 416 participants are shown in Table 11. The table shows a wide range of motivations. Some students focus on getting a good result on the exam, others focus on how the strategy helps them to study/learn, and still others want to identify relevant information or to learn about the task itself. The most common motivation is *to learn about the exam* (55.5 percent), followed by *to increase comprehension* (48.1 percent). To conclude, students had a lot of different motivations for engaging in a strategy and the most common ones were *learn about the exam* and *to increase comprehension* that were both listed by approximately half the students.

As can be seen in Table 11, some motivations indicate that the students want to increase their knowledge. These motivations are *to learn*, *restudy/good repetition* and *I learn well/better that way*.

Not all motivations by the students could be categorised, and some were therefore categorised as *missing*. In total 37.0 percent of the students had a missing motivation for a listed strategy. This results in some uncertainty about why these students use their strategies. This also indicates that some students have not reflected on why they use their strategies and therefore might lack awareness about their strategies.

The motivations shown in Table 11 are disconnected from the strategies they are connected to. To make a more in-depth analysis of the motivations, they are be presented with their connected strategies in Table 12 below.

Table 12: The most listed motivation for each strategy

Strategy	Motivation	Percent who listed	
Study old exams	To learn about the exam	63.3	(219)
	To identify what one is supposed to know/what is important	20.5	(71)
	To identify/test what one knows/comprehends and not	10.7	(37)
	It gives good/the best result, it works good/the best	8.7	(30)
Read course material/notes	It includes the most important/most relevant	23.7	(62)
	To increase comprehension	18.3	(48)
	To restudy/Good repetition	13.7	(36)
	To avoiding missing something/to include everything important	11.8	(31)
	To get an overview	11.5	(30)
	To identify what one is supposed to know/what is important	8.8	(23)
Do practice problems	It includes the most important/most relevant	23.2	(45)
	To learn it	13.4	(26)
	To increase comprehension	12.9	(25)
	It gives good/the best result, it works good/the best	12.4	(24)
	To practice	11.3	(22)
	To restudy/Good repetition	10.3	(20)
Summarise	To get an overview	23.8	(31)
	I learn good/better that way	17.7	(23)
	To restudy/Good repetition	12.3	(16)
Discuss with others	To increase comprehension	41.1	(30)
	I learn good/better that way	19.2	(14)
	To avoiding missing something/to include everything important	8.2	(6)
Flashcards/quiz	Good to memorise and/or remember	24.5	(12)
	I learn good/better that way	18.4	(9)
	To restudy/Good repetition	14.3	(7)
	It is easy (easy to implement, not very demanding)	14.3	(7)
Study in a group	To increase comprehension	23.5	(8)
	I learn good/better that way	14.7	(5)

Total number of students in parenthesis.

As Table 12 shows, students had different motivations for using a strategy. Some strategies had a wide range of motivations like *read course material/notes* with five motivations above ten percent while others like *discuss with others* that only have two motivations above ten percent. The most common motivation for *read course material/notes* was *it includes the most important/most relevant information* (23.7 percent), followed by *to increase comprehension* (18.3 percent). Examples of motivations that were different from *to increase comprehension* were *to get an overview* (11.5 percent) and *to avoiding missing something/to include everything important* (11.8 percent). These different motivations may affect the interpretation of the used strategy itself. For example, the strategy to *read course material/notes* might be interpreted differently depending on the motivation, as shown in comments (3, 4).

(3) *"Read through in order to understand the entirety of the course"*

(4) *"To get a quick overview of the course content"*

In comment (3) the student read in order *to increase comprehension* while in comment (4) the student read in order *to get an overview.* This indicates that it is hard to determine what the students do by only asking them to list their strategies.

To illustrate, the most used strategy, *study old exams*, was more frequently motivated as *to learn about the exam* with 63.3 percent of the students listed it, as shown in Table 12. This was the motivation with the highest percentage in all strategies. Examples of this motivation are shown in comments (5, 6).

(5) *"In other courses I have learned that often the exams are similar to each other and therefore this strategy is the most profitable"*

(6) *"To see how it is structured, what type of questions will come. To see if some questions are recurring and if so, maybe put down more time on that topic"*

These results indicate that the students wanted to learn the structure and content of the exams to be more prepared for it. Other motivations that were listed are *to identify what one is supposed to know/what is important* with 20.5 percent and *to identify/test what one knows/comprehends and not* with 10.7 percent. In general, it seems that *study old exams* was used to identify what was important to know and how they would be tested on this, which could be used for planning and goal setting. The strategy also seems to be used to evaluate one's knowledge by testing it in some way.

The third most used strategy, *do practice problems*, was instead motivated by a variety of reasons, as seen in Table 12. The most common motivation was *it includes the most important/most relevant information* with 23.2 percent listing it. Other used motivations for *practice problem* was *to learn it, to increase comprehension*, *to practice*, *restudy/good repetition* and *it gives good/the best result, it works well/the best*. The motivations for *do practice problems* had similarities to those for *read course material/notes* but not those for *study old exams*.

Two strategies similar to each other were *study old exams* and *practice problems*. They both consist of problems to solve. However, the motivations for using the strategies were different which is shown in Table 12. The strategy *study old exams*' three most used motivations were *to learn about the exam*, *to identify what one is supposed to know/what is important* and *to identify/test what one knows/comprehends and not*. While in the strategy *practice problems* the three most used motivations were *it includes the most important/most relevant information*, *to learn it* and *to increase comprehension*. In *study old exams* the students try to identify and gain information about the task while in *practice problems* they try to learn and understand something. The reason for this difference might be that the old exams give the students more information than practice problems. The old exams also provide valuable information about the examination itself like structure and available time.

Students also listed other interesting motivations. In the strategy do *practice problems* 6.2 percent listed that they use the strategy to *regulate level of difficulty*. *Summarise* was used *to identify/test what one knows/comprehends and not* by 5.4 percent (seven students). *Flashcards/quiz* was used *because it is fun* by 8.2 percent and only 3.6 percent used it *to identify/test what one knows/comprehends and not*. The strategy to *study in a group* had motivations like *easier to focus/spend time on* 8.8 percent, *because it is fun* 5.9 percent and *it feels good* 5.9 percent. Two examples for *easier to focus/spend time on* are shown in comments (7, 8).

(7) *"Together because I find it hard to study by myself"*

(8) *"I have a hard time putting down enough time and to focus when I study by myself, to study with 3 classmates makes it easier"*

This illustrates that some strategies were used to make it easier to put down time on studying. These motivations above further strengthen the claim that the students' used strategies for different reasons. It was surprising that *to identify/test what one knows/comprehends and not* was barely used in *flashcards/quiz* and that is was used more in s*ummarise.*

For each strategy, there were missing motivations. The number of missing motivations ranged between five to ten percent for most strategies. However, *restudy/repetition* and *study in a group* had a higher percentage of missing motivations with 23.6 and 17.6 percent respectively. This could indicate that the students had a harder time formulating a motivation for these strategies.

Finally, the motivations for the three most used strategies in each type of course were quite similar across programs. The most interesting difference was that bioengineering students motivated *read course material/notes* with *to increase comprehension* to a higher extent (36.7 percent) than civil engineering students (10.4 percent).

After Q2 in the questionnaire, which was the last question, the student was given the opportunity to write a comment. Out of all students, 17 percent (71 students) wrote a comment. The student comments were different from each other. Some helped gain an insight into the students reasoning while some did not. Some were also amusing. Some of the helpful comments are presented in the comments (9, 10, 11, 12).

(9) *"I think that my own strategies in general can improve, how I study varies to some extent for different courses"*

(10) *"I would like to get suggestions on study techniques from the teachers, for every course"*

(11) *"This gave me some new suggestions, but also made me realise some things I use"*

(12) *"It is easy, and one can do it everywhere, it does not take as much energy, but it does not help as much ether"*

In comment (9), the student stated that his/her strategies could be improved and that what strategies he/she used depended on the course. This shows that some students were aware that their strategies could be improved. In comment (10), the student expressed that he/she would like help on how to study in the different courses. This suggests that some students want to learn how to study more effectively and that the teacher could have an important role in this process. In comment (11), the student expressed that he/she learned something by completing the questionnaire. This is interesting because this suggests that the student started to reflect on why he/she used his/her strategies, which might increase the student's awareness of what strategies they use, by filling out the questionnaire. In comment (12), the student used a strategy because it was convenient and easily accessible even though he/she did not find it that helpful. This indicates that some students did not chose strategies based only on effectiveness but also for other reasons like the convenience and the situation. For other interesting or amusing comments see Attachment B.

4.3 Rating of effectiveness of learning strategies (RQ3)

In this section, the result for RQ3 is presented. RQ3 stated: How aware are the students of the effectiveness of their strategies?

All 416 students were asked to rate the effectiveness of seven learning strategies, chosen based on Dunlosky et al. (2013). They only rated the strategies they used and did so on a scale from one to six, where one represented low effectiveness and six high effectiveness. The result is shown in Table 13, where also Dunlosky et al.'s (2013) rating is included.

Table 13: Students' rating of the effectiveness of their learning strategies in comparison to Dunlosky et al.'s (2013) rating

Strategy	Rating by Dunlosky et al. (2013)	Mean. Student rating	Std. Deviation	Number of students
Practice testing	High	5.12	0.950	303
Self-explanation	Moderate	4.96	0.978	217
Elaborative interrogation	Moderate	4.90	1.013	196
Summarisation	Low	4.84	1.113	235
Keyword mnemonic	Low	4.60	1.114	171
Rereading	Low	4.26	1.181	318
Highlighting/underlining	Low	3.66	1.269	118

As shown in Table 13, all strategies were rated higher than 3.5 on average, which is above the mean value on the scale. The students rated the effectiveness of the strategies in the same order as Dunlosky et al. (2013) with *practice testing* as the most effective to *highlighting/underlining* as least effective. However, note that Dunlosky et al. (2013) only had three levels of ratings. To conclude, the students consider the strategies to have different effectiveness. The average rating of each strategy was higher than 3.5 which suggests that they in average find all strategies they use to be effective to some extent. They rated the strategies in the same order as Dunlosky et al. (2013) in regards to effectiveness.

Some strategies shown in Table 13 were used by more students than others. The most used strategies were *rereading* with 318 and *practice testing* with 303 students who used and rated the strategies. The least used strategy was *highlighting/underlining* with 118 students who rated it.

By comparing students' rating of one strategy with their rating of another strategy one can see which strategy they believed to be the most effective of the two. This comparison was done with the students that used both *practice testing* and *rereading* to see which one the individual student on average consider to be the most effective. 255 students out of 416 reported using both strategies. Of these students, 63 percent rated *practice testing* as more effective than *rereading,* 15 percent rated rereading as more effective and 22 percent rated both equally effective. This shows that most students that used both strategies considered *practice testing* more effective than *rereading*.

Within each strategy in Table 13 above, there is a distribution of students rating of effectiveness from one to six. How many students that rated each level is shown in Table 14 below.

Table 14: Distribution of students' rating of effectiveness within each strategy

Strategy	Number of students that rated the effectiveness of a strategy to be either (1), (2), (3), (4), (5) or (6)					
	(1)	(2)	(3)	(4)	(5)	(6)
Practice testing	1	3	13	53	104	129
Self-explanation	0	2	20	36	86	73
Elaborative interrogation	1	1	15	50	62	67
Summarisation	2	6	22	45	83	77
Keyword mnemonic	2	4	22	44	60	39
Rereading	4	16	65	93	87	53
Highlighting/underlining	3	21	28	39	15	12

As shown in Table 14, some students used strategies that they rated as having low effectiveness. In total, 66 students mentioned using a strategy that they rated as having an effectiveness of one or two which can be considered low effectiveness. Most of the low effectiveness ratings belonged to *rereading* and *highlighting/underlining*. One student comment on using highlighting as shown in comment (13).

(13) *"highlighting helps only to find back to the things I considered to be important in order to write it down"*

In comment (13), the student suggested that *highlighting/underlining* is used to identify/find the information again rather than a way of learning the information. This shows that some students used strategies they consider to not to be effective for learning. However, they might still benefit from the strategy by identifying what to learn or finding back to the highlighted information quicker than if it had not been highlighted.

5 Discussion

This thesis aimed to (1) map what learning strategies engineering students use in a real-world setting, in real courses; (2) investigate the students' motivation for choosing certain learning strategies and (3) probe their metacognitive awareness of the effectiveness of different learning strategies. It also aimed to investigate if differences could be seen across engineering programs or across two types of courses (calculation courses and conceptual courses). The participants, 416 engineering students, answered a questionnaire where they listed the learning strategies they used in a specific course, motivated why they used them and rated the effectiveness of some of the strategies they used. Then, all the answers to the open response questions were categorised before the data was analysed. The learning strategies were compared across programs and types of courses both descriptively and with statistical tests. The motivations were analysed by comparing the categories with previous research on students' use of learning strategies, research on the effectiveness of some learning strategies and theories on SRL and metacognition. Students' rating of the effectiveness of their learning strategies was also compared to theories and previous research.

Our results revealed a complex picture of what learning strategies students use and why. It also revealed that what learning strategies students used varied across courses but not across programs. Overall, to *study old exams* was the most used strategy. It was used mostly to obtain knowledge about the exam, but also to identify what was important and to test oneself. The second most used strategy was to *read course material or notes*, the third was to *do practice problems* and the fourth *summarising*. These strategies were motivated in quite different ways by the students. Even when investigating students' use of only a single strategy, a wide range of motivations was listed. This was true for several strategies and suggests that many strategies might not be single strategies but many different. Regarding students' awareness of the effectiveness of strategies they used, the results show that students in average are quite aware. However, some students rated strategies they used as having low effectiveness. As an example of the students' awareness in average, *highlighting/underlining* and *rereading*, which was rated as having low effectiveness by Dunlosky et al. (2013), were rated the lowest. *Practice testing* on the other hand was rated the highest and has also been shown effective in previous research (Dunlosky et al., 2013; Karpicke et al., 2009). Thus, this study confirms the results of prior research on learning strategies to a large extent. In the following sub-sections, the results presented above are discussed in the light of the three research questions.

5.1 RQ1: What is the distribution of reported learning strategies across engineering programs and types of courses?

In general, to *study old exams*, *read course material/notes*, *do practice problems* and *summarising* were the four most used strategies. In previous research, to *study old exams* has rarely been included or identified, even though Gurung et al. (2010) did so. *Read course material/notes* on the other hand has been found to be a common strategy in several studies (see for example Carrier, 2003; Gurung, 2005; Karpicke et al., 2009). This is in line with our result, even though for example Karpicke et al. (2009) reported *rereading* as a strategy rather than to *read course material/notes*. Some of the participants did state that they reread, but these were very few. Note that this previous research is in line with what we found in conceptual courses mostly, which could be expected as it has been done on students enrolled in conceptual courses rather than calculation courses. However, these similarities and differences compared to previous research depending on type of course also points out that context might be an important factor for students' choice of strategies.

No statistically significant difference was found between the two programs. This might be because the programs are after all both engineering programs. They, as typical engineering programs, start with general engineering coursework before they then become more specific over time (Grohs et al., 2018). As our participants were first- and second-year students, their education so far could therefore be quite similar despite the different specialisations. The context was in other words possibly not different enough to affect what learning strategies students used. In addition, all students would have had to have quite high grades to be admitted to the university and were therefore similar in that sense too.

There was on the other hand a difference across types of courses in what learning strategies students listed. The most common strategy, to *study old exams*, was widely used in all courses, while to *do practice problems* was used mostly in the calculation courses and both to *read course material/notes* and *summarising* were mostly used in the conceptual courses. However, the difference across types of courses was not very surprising, as the content is very different and students in calculation courses usually get a list of problems to solve while those in conceptual courses get a list of pages to read. In both types of courses, it is in our experience very common that the teacher provides students with old exams. While engineering education has some common features in the beginning of the education, the courses within a program can still be very different (Grohs et al., 2018). The difference in context could therefore be considered larger across types of courses than across programs in at least the first year. This could explain why type of course but not program made a difference to what learning strategies our participants used. Our findings that context matters is in line with previous research were students have been shown to adapt their learning strategies depending on the learning situation (Schmeck & Geisler-Brenstein, 1989) and suggested to do the same depending on context (A. F. Hadwin et al., 2001; Van Etten et al., 1997).

A few things in our results indicate that some strategies may be more common or unusual in specific courses depending on the material available. In the conceptual course for the bioengineering students, the teacher did not provide students with old exams, according to the teacher himself, and indeed this was also the course where the fewest students listed that strategy. *Flashcards/quizzes*, on the other hand, were very popular in the conceptual course in the civil engineering program, where already made flashcards for that specific course were available online. This made the strategy much easier to use than if students would have had to make their own flashcards, and that is probably why so many students in that course listed this strategy. As is exemplified by student comment (1) and (2), which are both from the civil engineering conceptual course, this was also how the students themselves motivated their use of flashcards. This result shows that not only the type of course matters, but many other factors may also influence students' choice of learning strategies.

The civil engineering conceptual course was also the only course where *study old exams* was the most used strategy. This might be explained by the demands of the exam. All courses except for this one entailed one big exam at the end of the course, including all course content. Instead, this course had a slightly smaller exam earlier in the course, including only part of the total content of the course, and then an essay at the end of the course. As Gurung et al. (2010) suggested, how advanced both the course and the exam are might affect what strategies students use. They exemplified *studying practice exams* as a basic strategy that could be enough for a not very demanding exam. This is in line with our findings, and also with Abd-El-Fattah's (2011) findings that students adapt their strategies to the cognitive processing demands of the exam. It is however difficult for us to conclude the level of this exam, even though some students suggested it was not very demanding.

In conclusion, the students did adapt their strategies to context, both regarding which type of course they were enrolled in and what tools were available. The lack of difference across programs may be explained by context and students' being quite similar in both programs.

5.2 RQ2: What motivates the students' choice of strategies?

Students listed a broad range of motivations to why they use their strategies. The motivations were quite similar across programs. Some strategies, for example *to increase comprehension*, were common for several strategies while some were very specific for certain strategies. The most common motivation, *to learn about the exam*, was very specific for the strategy to *study old exams*. When comparing the students' motivations to research on learning strategies, it was clear the strategies were used for different purposes. For example, some motivations suggested a strategy was used to increase knowledge - in other words as a cognitive strategy (Flavell, 1979), while some were rather used to plan, monitor or evaluate knowledge - in other words as metacognitive strategies (Flavell, 1979). We will in this section discuss the motivations for some of the most common strategies and what the motivations may tell us about how students use their listed strategies.

Many strategies were motivated in different ways by different students, suggesting they should not be considered one but several strategies. It is also important to note that one strategy could have several motivations for the same student. One example that shows that strategies can be used in very different ways by different students is that the students who used *read course material/notes* and motivated it by *to increase comprehension* might read in a completely different way than students who use it *to get an overview*. In the first case, students might read thoroughly and really try to ask themselves what the text means and try to make sense out of it by trying to connect it to their previous knowledge. In contrast, students who *read course material/notes to get an overview* might skim through pages, and maybe only read headings and look at figures. This suggests reading cannot be considered one strategy but should rather be considered several different strategies, as in Wade et al.'s (1990) study.

The most often used strategy, to *study old exams*, was also used in several different ways, whereof many could be considered metacognitive strategies. Students used *study old exams* mostly *to learn about the exam*, *to identify what is important* and *to identify/test what one knows/comprehends and not*. The motivation *to learn about the exam* implies students used the strategy to gain knowledge about the task (the exam) and what is expected of them. Therefore, it suggests these students used *study old exams* as a metacognitive strategy (Flavell, 1979) and as a part of the forethought phase of SRL, where students plan and set goals for their learning (Zimmerman, 2008). Students who studied old exams *to identify what one is supposed to know/what is important* can also be considered to use it as metacognitive strategy, as it provides students with knowledge about what they need to study (Flavell, 1979). It is quite similar to the motivation *to identify/test what one knows/comprehends and not*, only that testing aims at evaluating what you have learned while *to identify what one is supposed to know/what is important* is probably used in the initial phase of the learning process to identify the most important things to learn. Both provide students with knowledge that can guide further studying and are therefore important parts in monitoring and regulating their own learning (Flavell, 1979; Zimmerman, 2008). *To identify what one is supposed to know/what is important* could be part of the forethought phase of SRL, where students plan and set goals, while *to identify/test what one knows/comprehends and not* is instead part of the self-evaluation phase (Zimmerman, 2008). The students who *study old exams* for these purposes show metacognitive awareness of the importance of directing their learning. Whether students who motivated the strategy with the fourth most common motivation, *it gives good results*, were correct is unclear as we did not investigate achievement, but a previous study suggested it gave good results for engineering students in another type of course (Gurung et al., 2010) so they might as well be. To conclude, students used *study old exams* mostly as a metacognitive strategy and mainly as part of the forethought and self-evaluation phases of SRL. This highlights the importance of asking students why they study as they do and not only what they do, as these differences was revealed only when combining the strategy with the students' motivations.

As opposed to *study old exams*, *do practice problems* was used mostly as a cognitive strategy to increase knowledge (Flavell, 1979), even though some students used it as a metacognitive strategy as they motivated it *to increase comprehension*. Examples of one kind of motivation common for this strategy, that indicates students used the strategy to increase their knowledge, include *I learn well/better that way, to restudy/good repetition, to learn it* and *good to memorise and /or remember*. The strategies motivated with this kind of motivation, including the strategy *to do practice problems*, could have been selected by the students in the forethought phase of SRL, and thereby be part of the performance phase (Zimmerman, 2008). As we did not ask how they used strategies in combination, this is hard to know. Another common motivation for *do practice problems* was *to increase comprehension*. This motivation is less straightforward to interpret than many of the other motivations. When students not only try to learn content but also try to understand it, this process inevitably includes some sort of metacognitive monitoring of their own comprehension of the material, in this case practice problems. They first have to be aware that they need to increase their comprehension to initiate the activity, and then monitor their comprehension when they do the practice problems. As part of increasing their comprehension, they are probably also increasing their knowledge, which suggests the strategy is also cognitive (Flavell, 1979). In other words, they metacognitively monitor their comprehension while increasing their knowledge by performing cognitive strategies in the performance phase of SRL (Flavell, 1979; Zimmerman, 2008). This is very much in line with Flavell's (1979) definition that one strategy might be used in order to achieve a cognitive or metacognitive goal or both types of goals, whereof the later seems to be the case here.

When comparing *to do practice problems* to *study old exams*, which could be at first sight be considered as similar strategies in the calculation courses, it is also important to notice that these strategies are not only used in several different ways within themselves. Even though some students may use them in similar ways, the overall conclusion is still that students use these strategies for quite different purposes, despite their similarities.

Some strategies were used not only for as cognitive or metacognitive strategies, but rather as strategies aiming to self-regulate behaviour and motivation. One strategy that highlights this was *to study in a group*. As *discuss with others*, it was used *to increase comprehension*, for example by getting new perspectives from other students, which is similar to what Van Etten et al. (1997) found about students' perceptions of the benefits of studying in a group. A previous study on engineering students in a statistical course however found that students who mainly solved problems by themselves performed better than students who mainly solved problems together with peers (Grohs et al., 2018). This could suggest students in our study used a strategy they thought was effective, but that was in fact not. We did not investigate this, but if it was to be true for our participants, their judgement may stem from metacognitive illusions that make them misjudge their learning (Serra & Metcalfe, 2009).

However, *study in a group* had one kind of motivation, that was also listed for some other strategies, that *discuss with others* did not. Some students used this strategy to actually do something instead of not doing anything, as they wrote that it is *easier to focus/spend time on* or *it feels good*, as indicated by student comment (7) and (8). In other words, they used this strategy to regulate their behaviour and motivation, which makes it an SRL-strategy for those students (Pintrich, 2000). Another example of a motivation that indicates a strategy was used to regulate behaviour is *it includes the most important/most relevant information*, which may limit the time students have to spend studying and thereby suggests regulation of behaviour. A final example is student comment (13), where the student says he/she does not use highlighting as a strategy on its own, but rather to make it easier to find back to the important things, in other words to minimise the time that takes. The two last examples also show that students used strategies that they thought were effective not in the sense that they learned much content per time unit, but in order to minimise the amount of time certain strategies take. To conclude, students did not only use strategies for cognitive or metacognitive purposes but also to self-regulate behaviour and motivation. This is important to have in mind when trying to draw conclusions on students' metacognitive awareness of the effectiveness of different learning strategies, as their use of strategies might be misleading without follow-up questions on why they use them.

To connect to Karpicke et al.'s (2009) focus on testing it is interesting to look at the motivation *to identify/test what one knows/comprehends and not.* While *flashcards/quiz* was mostly used to memorise, not *to identify/test what one knows/comprehends and not*, testing was a relatively common motivation overall. The fact that *flashcards/quiz* was not used to practice testing is in line with what Wissman et al. (2012) found and what Karpicke et al. (2009) suggested. However, about 19 percent of our participants motivated a strategy (in most cases not *flashcards/quiz*) with *to identify/test what one knows/comprehends and not*, in other world used their strategy for self-evaluation. For example, seven students in our study used *summarising* to test themselves, a use of summarising highlighted also by Dunlosky et al. (2013). Similarly, Granescu and Literat (2013) found that 20 percent of their participants used self-evaluation of some sort. On the contrary, Gurung (2005) found testing knowledge to be one of the least used strategies. This was true in our study as well, regarding the strategy *practice testing*. Nevertheless, the motivations revealed that students either used strategies they did not list as practice testing to actually practice testing or that they did not list all of their strategies. For example, *to study old exams, to do practice problems* and *summarising* were all motivated with *to identify/test what one knows/comprehends and not* by some students.

To summarise, there is a broad range as to how students motivate why the use their strategies. This is also true within strategies. Based on the students' motivations, we found examples of strategies from all three phases of SRL and aiming at both cognitive and metacognitive goals. In addition, some students motivated certain strategies in a way that indicated that they regulated their behaviour or motivation by using these strategies. Some students also used strategies for several purposes at once. These results further emphasise the importance of not only asking students what they do, but also why they do it.

5.3 RQ3: How aware are the students of the effectiveness of their strategies?

As shown in Table 13 in section 4.3 Rating of effectiveness of learning strategies (RQ3), the strategy rated as being highly effective by Dunlosky et al. (2013) got the highest average rating by the students and the ones rated as having moderate effectiveness got a little lower rating. Finally the ones rated as having low utility by Dunlosky et al. (2013) got the lowest average rating by the students. *Summarisation* was rated higher by the students than the rest of the strategies rated as having low effectiveness by Dunlosky et al. (2013), and almost as high as *elaborative interrogation*. This was also in line with Dunlosky et al. (2013), as they suggested *summarising* might deserve a higher rating for undergraduates that are skilled at summarising. The average ratings were all above 3.5, which suggests students in average thought all strategies were at least moderately effective. This is not in line with Dunlosky et al.'s (2013) rating, but it is important to note that students only rated the strategies they used, which suggests they should find the strategies useful in some way. Students who did not report using the strategies might have rated them lower than the students who used them, which would have lowered the average rating.

However, some students reported to use strategies they themselves rated as having low effectiveness. This suggests student awareness might not always be consistent with what they do. For example, 318 students reported that they used *rereading* as a strategy, which made it the most used strategy of the ones listed, but still they rated it quite low. One explanation for this is the reason stated in student comment (12), that he/she found the strategy easy to use everywhere and not very demanding but was aware it was not that effective. Possibly, the alternative to use this strategy would in some situations be to do nothing. This suggests students do not only choose strategies based on how effective they think the strategies are, but also based on the situation. This is in line with Van Etten et al.'s (1997) conclusion that students sometimes are aware of the benefits of certain strategies but still do not always use that knowledge. It is also in line with our conclusions in section 5.2 RQ2: What motivates the students' choice of strategies?, that students not only use strategies for cognitive or metacognitive purposes but also to self-regulate behaviour and motivation and that effectiveness also may mean to actually make oneself spend time studying or minimise the time needed for certain learning activities.

As the strategy *practice testing* in this part of our study not only include the testing effect but also to test for feedback, it is hard to compare it directly to Karpicke et al. (2009). However, while Karpicke et al. (2009) suggested that students lack metacognitive awareness of the testing effect, our study suggests students are metacognitively aware of the effectiveness of testing. This should be of greater importance as testing for feedback is even more effective than testing without the possibility to restudy (Dunlosky et al., 2013). In addition, our results suggest that a majority of the students who use both *practice testing* and *rereading* think testing is more effective. Karpicke et al. (2009) made testing an unattractive alternative, when students could not choose to both test and restudy. As we instead asked students to rate their strategies, we might have caught their awareness more accurately. On the other hand, we also found examples in line with Karpicke et al.'s (2009) suggestion that students are not aware of what learning strategies are effective. Even though the average result on Q2 suggested students are aware of the effectiveness of their learning strategies, there were students that found *practice testing* to be ineffective but *rereading* to be highly effective. In conclusion, our results speak in favour of our participants' metacognitive awareness of the effectiveness of their strategies, even if this is not true for every single student.

5.4 Limitations

Even though the preliminary design of the questionnaire was evaluated by conducting a pilot survey with a focus group to make sure students would interpret the questions the same way as us, it is possible that not all 416 participants did so. In addition, the last question, Q2, was changed drastically after the pilot survey and not evaluated in the same organised way as the first questions. However, we obtained almost no indications from the students' answers suggesting they had misunderstood the questions. Still, some students might have misinterpreted the first question, Q1, and listed the strategies in the order they use them or from the ones they think are the most important to the ones they think are the least important instead of listing them from the most often used to the least often used. This risk was minimised by explaining this part of the question both in text and orally when introducing the survey to them. In addition, at least one of us, or in one case an assistant with good knowledge of the survey, was available in the room in case any questions would arise.

The survey was executed during mandatory occasions in the calculation course in bioengineering and the conceptual course in civil engineering. In the remaining two courses, it was conducted during lectures that were not mandatory. This clearly affected the response rate in these courses negatively. Possibly, students who chose not to go to these lectures might have used somewhat different learning strategies, if they had actively chosen not to attend the lectures.

The students were only asked to rate the effectiveness for strategies they used in the course they answered the questionnaire for. Even though it is not a limitation to the current design, it could have added further value to this thesis to see what the students thought of the effectiveness of the strategies they did not use. It could have provided additional input on students' metacognitive awareness and reasons for choosing to use or not use certain strategies. Students' might have chosen not to use strategies they do not find effective, but we do not know that.

As two of the survey questions were open response questions, there is a chance that some answers were misinterpreted. However, the intercoder reliability was very high which suggests this was not a big issue.

Regarding context, there are a few obvious limitations. First, the two conceptual courses were not identical, as were not the calculation courses. This might have affected the comparison across programs, as courses were assumed to be comparable. Second, the conceptual courses were part of the second year of each program respectively, while the calculation courses were part of the first year. As was suggested by the students in the pilot survey, students might change their strategies over time and with increased experience, meaning this difference could have affected the result so that the difference between courses became larger. Finally, the teachers were not the same in the courses of the same type. As Bielaczyc et al. (1995) stated, teachers may change students' choice of strategies with deliberate teaching. Whether the teachers in these courses actively tried to affect students' strategies and to which extend was not investigated in this study but might have affected the results.

Regarding generalisability, the small number of courses and programs makes it difficult to draw any general conclusions on students learning strategies in engineering education in general. All participants were also students in the same university and in their first or second year at their program. However, our results and conclusions may still give teachers and researchers a suggestion for how engineering students might study in these particular types of courses, especially the first- and second-year students. More research is needed in different contexts to further increase the comprehension of engineering students' use of learning strategies.

Finally, this study has the same limitation regarding method as other studies using self-report questionnaires. As Winne and Jamieson-Noel (2002) and Winne and Jamieson-Noel (2003) concluded, self-report data might not be completely accurate as it is based on the students' perception of what they do. Students may for example inaccurately approximate the time they spend on each strategy (Winne & Jamieson-Noel, 2002) or how often they use them, which would affect our result.

5.5 Conclusion

To conclude this thesis, in this section we will answer the three research questions shortly, discuss some further implications of our findings, state our contribution and finally give some suggestions for future research.

Regarding the distribution of reported learning strategies across engineering programs and types of courses (RQ1), a difference was found across types of courses but not programs. This means students adapt their strategies based on the context and the material to be learned. To *do practice problems* was for example common in the calculation courses while to *read course material/notes* was common in the conceptual courses. The students' motivations for their choice of strategies (RQ2), showed that students motivated their strategies in a number of different ways. The motivations did not only explain why they used their strategies but also how. Some motivations suggested students used a strategy to reach a cognitive goal, while other motivations for the same strategy suggested it was used to reach a metacognitive goal. This suggests that some strategies are not only one but several strategies. The most common motivation was *to learn about the exam*, which suggests that students find it important to learn about the task at hand to be able to plan and set goals for their learning and thereby engage in self-regulation. Our findings also suggest that students not only adapt their strategies to the type of course, but also to the situation and therefore sometimes use strategies they believe to be less effective in some senses. Additionally, some students use strategies to actively regulate their behaviour and motivation. Finally, the students in general were shown to be aware of the effectiveness of different strategies (RQ3), while some students instead showed a lack of awareness regarding certain strategies.

An interesting remark is that students by simply completing the questionnaire may have started to reflect more upon their own learning, as exemplified in student comments (9) and (11). Note that the questionnaire did not suggest anything about what strategies may be considered effective and which may not, and that two out of three questions were open response questions designed to capture what students do and why without affecting their answers too much. Previous research has pointed out that there are many benefits for engineering students to engage in metacognitive activities, which reflecting upon their own learning indeed is (Grohs et al., 2018). Our questionnaire takes almost no time to complete, only 10 to 15 minutes, but still may start a process.

As suggested by student comment (11), students may use strategies they have not really thought about. This was also something we suspected when conducting the survey, as many students seemed to find it really hard to answer the questions when we observed them writing their answers, but still many students motivated their choices in ways that showed both metacognitive awareness and suggested that they at least partly self-regulated their learning. Perhaps they regulate their learning and engage in metacognitive strategies unconsciously, as Flavell (1979) suggested. That does not have to mean that they are not good at it, but they could probably benefit from doing it more consciously and being more aware of how they make their choices. What they do might also be partly regulated by their social environment Hadwin, Järvelä, & Miller (Hadwin, Järvelä, & Miller, 2018), as students learn from each other and older students what learning strategies are effective to use. This could be of even greater importance at Chalmers University of Technology, where traditions promote this transfer of knowledge between old and new students. In one previous study, many teachers in engineering education pointed out that they thought the social context was important for engineering students to succeed (Ferrare & Miller, 2019). These aspects, both the social aspect and how consciously students regulate their learning, could be interesting for future research to look into, as suggested at the end of this section.

Another important aspect of students' learning strategies outside class is what happens in class, in other words the teachers' role in what learning strategies students use (Bielaczyc et al., 1995). To connect to the engineering education context, it is worth noticing that teacher's views on learning and teaching have been shown important for students' persistence in STEM-courses (Ferrare & Miller, 2019). The teacher's role was also highlighted by a student in our study, who commented that he/she would have liked to get support from the teacher on which learning strategies to use, in every course (see student comment 10). The student seems to have been aware of the importance of context but wanted help. It could be argued that students get this help to some extent already, if teachers provide them with pages to read, problems to solve or old exams to study. These materials could however be used in a number of different ways, which hardly makes them strategies in themselves. It is possible that teachers try to affect what students do also in how they design their lectures, what tasks they choose to be part of the course and at what time and so on, but if so, this might be something they do not explain to the students. Therefore, the students might not notice it. To be able to affect what strategies students use, teachers would also have to have an idea of how they want students to study, which suggests that teachers themselves for example have to have knowledge about the effectiveness of different strategies. In other words, the teachers have to self-regulate their own teaching and learning to support students learning (Kramarski, 2018). This regulation and support is probably easier to achieve if they actually know what learning strategies their typical students use and how. Possibly they could guess this, but they might as well be incorrect. To resolve this, they could use our questionnaire to get knowledge of what their students do outside class to learn the content of their specific course and use this knowledge to design their teaching to better support students' learning. If the teachers succeed in supporting engineering students' use of metacognitive strategies they may also give more metacognitive feedback, which has been shown to be beneficial for engineering students (Grohs et al., 2018).

This thesis contributes to the research on learning strategies in general and engineering students' strategies in particular by increasing our understanding of both what students do and why they do so. We have not only mapped what strategies engineering students use, but also investigated how and why they use them, how aware they are of the effectiveness of their strategies, and if they adapt their strategies to the type of course. By doing so, we have acquired a complex picture of students' choice and use of learning strategies. In addition, the questionnaire developed is a contribution in itself, as it constitutes a theory and research-based tool which, as advocated by Hadwin et al. (2001), takes into account the context of learning (both type of course and program). Furthermore, as students are also asked why they use their strategies and to rate the effectiveness of some of their strategies, the questionnaire makes it possible to dig deeper into students' learning strategies outside class and the presumably sometimes complex reasons why they do so. The questionnaire also forces the students to reflect upon their own learning, which might in itself be beneficial.

In conclusion, this study increases our understanding of engineering students' learning strategies and thereby provides important knowledge both for teachers to regulate their teaching and for researchers to design effective interventions. The questionnaire could be used to further increase this knowledge and thereby help providing an even better base for improving teaching to better support students learning and for designing effective interventions.

Future research could expand the complex mapping of students' learning strategies outside class to other types of courses in engineering education, to compare it across years and also expand it into other types of education, both higher education and for example high school and adult education. In addition to mapping strategies one by one, it would be interesting to map the whole process of what strategies students use in which order and why, even though some more recent research has done this to some extent (Molenaar & Järvelä, 2014). Future research could also investigate the teachers' role in relation to which learning strategies students use, and design interventions aiming to improve students' learning by either making the teachers support the students' choice of strategies or making the students themselves reflect more upon their learning. Finally, future research could combine our questionnaire with focus groups or individual interviews to further increase the understanding of what students actually do and why. This could also give insight into how conscious the students' choices are and what role their social environment play.

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Attachment A

Enkät om lärandestrategier

Vi är två studenter på mastersprogrammet Lärande och ledarskap som gör mastersarbete (exjobb) på institutionen för vetenskapens kommunikation och lärande och undersöker vilka strategier studenter på Chalmers använder när de pluggar. Vi skulle därför behöva din hjälp genom att du svarar på frågorna nedan om hur just du pluggar i kursen KMG050 - Cell- och molekylärbiologi 2. Enkäten består av några bakgrundsfrågor samt två större frågor och tar ungefär 10 minuter att fylla i. Läs igenom frågorna ordentligt och svara så uppriktigt du kan.

Enkäten besvaras anonymt. Inga uppgifter som möjliggör identifiering av dig som besvarar enkäten kommer samlas in och din föreläsare eller examinator kommer inte ha tillgång till dina enkätsvar. Genom att besvara enkäten godkänner du att dina svar används i vårt mastersarbete samt för forskning.

Bakgrundsfrågor:

☐ Kvinna ☐ Man ☐ Annan könsidentitet

Vilket program läser du?

☐ Bioteknik, civilingenjör

☐ Annat *(ange detta)*:___________________________

Hur många år har du studerat på universitetet, detta läsår inräknat?
Tekniskt basår räknas inte in i denna fråga.

☐ 1 år ☐ 2 år ☐ Mer än 2 år

Har du läst tekniskt basår?

☐ Ja ☐ Nej

Fråga 1a:

Vilka strategier använder du när du pluggar inför tentan i kursen KMG050 - Cell- och molekylärbiologi 2? Lista alla strategier du använder och rangordna dem från de du använder oftast till de du använder minst ofta.

Fråga 1b:

Motivera för var och en av dina tre oftast använda strategier varför du använder just dem? (Har du listat färre än tre strategier, motivera då för de du listat.)

Fråga 2:

Besvara frågan genom att följa de två stegen nedan. Har du kommentarer finns det möjlighet att skriva dem längst ner på sidan.

1) Läs strategierna noga och kryssa i vilka av dem du använder i kursen KMG050 - Cell- och molekylärbiologi 2.
2) Hur effektiva tror du att strategierna du kryssat i är för att lära sig det som kommer på tentan I kursen KMG050 - Cell- och molekylärbiologi 2? Ringa in en siffra för var och en av strategierna du använder.

Jag använder den här strategin									
☐	Identifiera/komma på nyckelord och skapa mentala bilder av dessa för att komma ihåg/lära sig informationen nyckelorden kopplar till	Låg effektivitet	1	2	3	4	5	6	Hög effektivitet
☐	Skriva sammanfattningar	Låg effektivitet	1	2	3	4	5	6	Hög effektivitet
☐	Kontrollera vad man kan av kursinnehållet genom att testa sig själv på det	Låg effektivitet	1	2	3	4	5	6	Hög effektivitet
☐	Läsa igenom kursmaterial och/eller egna anteckningar mer än en gång	Låg effektivitet	1	2	3	4	5	6	Hög effektivitet
☐	Stryka under eller över (highlighta) i böcker eller anteckningar	Låg effektivitet	1	2	3	4	5	6	Hög effektivitet
☐	Försöka förklara för sig själv varför fakta eller koncept är sanna/stämmer	Låg effektivitet	1	2	3	4	5	6	Hög effektivitet
☐	Förklara för sig själv hur ny information hänger ihop med gammal eller förklara de olika steg man tagit när man löst ett problem/en uppgift	Låg effektivitet	1	2	3	4	5	6	Hög effektivitet

Eventuell kommentar *(fortsätt på nästa sida om du behöver mer plats)*:

(Fortsättning på eventuell kommentar)

Attachment B

Below, examples of students' comments and motivations are presented. Some are insightful while others are interesting or amusing.

> *'"I went deeper where I thought the lectures did not cover all the content and where I wanted to learn more"*
>
> *"If something is hard or when one has not taken notes of something it can be good to hear it in another way"*
>
> *"When discussing with classmates one explains to each other or provide insights into things that may not be previously understood"*
>
> *"Watched Khan academy to understand the things I missed in the old exams"*
>
> *"Good to go back to notes and so on in order to see what one needs to know"*
>
> *"In order to restudy everything that the teacher have presented"*
>
> *"One gets an overview of what the exam will be about. Has worked on other exam"*
>
> *"The book is in English and it is harder to understand examples and theories. Therefore, I use notes instead"*
>
> *"Examples from the lectures are what the teacher think is important and therefore it is likelier to appear on the exam"*
>
> *"Extra motivation to actually study when you are with your classmates"*
>
> *"Study in a group – creates peer pressure to work and it is more fun"*
>
> *"We usually discuss the more extensive problems and solve it together if we do not get it"*
>
> *"I like small digitalised test, because then I do not need to bring all the books in order to study and can do it whenever I want"*
>
> *"do not like diagnostic exams, do not suit my learning style, creates stress"*
>
> *"there are a lot of facts in lectures and literature that you do not need for the exam. Therefore, it is unnecessary to study on that, you do not have time. Usually the type of exam is similar"*
>
> *"One does not remember everything you write the first time.* "Repetition is the mother of knowledge." *Statement from a high school teacher that cited someone else"*

“It sticks better to my memory when I visualise the information”

”The most effective according to me is to test yourself in different ways in order to find out what you know/need to practice more on”

”One does not test oneself do to learn and it is only for checking what one knows”

”I read through notes, but rarely more than one time”

“To read course literature is a strategy for those who have not adapted to university, totally unnecessary, expensive but sometimes also important”

“video lectures because I learn much. Same knowledge in 10 minutes as in a 1 hour and 30 minutes lecture”

“Work 45 minutes and rest 15 minutes because research indicates that we cannot work actively for longer periods of time”

”Focus on other things, many balls in the air and a lack of interest for the subject”

Procrastination:
“I often finishing the assignments and prepare for the exam at the last minute. But I study effective for a few hours before exam, has worked in the past”

“It will lead me onto the right path”

“The way of university is that you have to study old exams. It does not matter how much you understood on the lectures”

“I have 3 children and a messy apartment”

“In the beginning you try to follow everything in the course but then you give up and take everything in the end”

“I learn the most by doing mistakes”

“If I am at home, I will not get anything done”

“Everyone helps to drag everyone forward, like in cross country skiing. Ten kilometres are easier to do in a group”

“Rest body and brain → increase focus”