Self-regulated learning in mathematics tertiary education

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Eigenständigkeitserklärung

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Abstract

A high number of engineering graduates is desirable both from the individual students' views as well as from an economic and societal view. However, on their way to graduation, engineering students encounter a variety of challenges. One of them are mathematics courses, which are a typical and often obligatory part of engineering degree programs in Germany and other countries. Many of the explanations which have been provided for students' difficulties in mathematics courses can be subsumed under the umbrella term of self-regulated learning. Although self-regulated learning is an intensively researched field, the literature base has several important limitations which impede the application of this knowledge to improve mathematics tertiary education. This dissertation wants to overcome these limitations and thus contribute to enhance the success of (engineering) students in mathematics tertiary education.

In the first study, a systematic review of research in the field of self-regulated learning in mathematics tertiary education in this millennium was conducted. Several databases containing both psychological as well as mathematics research were systematically searched. In addition, exploratory searches were conducted. After applying a two-tier screening procedure to the references identified, 28 articles remained as the final sample. Coding articles using a standardized coding sheet allowed to describe the literature base regarding research topics addressed, theories used as a basis for research or argumentation, definitions provided and aspects of self-regulated learning focused on, research design and measurement instruments used, as well as groups targeted by the research. Based on this, conclusions regarding the nature and correlates of self-regulated learning in mathematics tertiary education as well as possibilities to support it could be drawn.

In the second study, semi-structured interviews with engineering students enrolled in a mathematics course at a German university of technology were conducted. The final sample included 27 students. Anonymized transcripts were coded and analyzed using a deductive-inductive process. This allowed to identify important (meta-)cognitive and resource management strategies students used in mathematics courses. Reasons for (non-)use, way and frequency of use as well as perceived helpfulness could be explored for several learning offers. In addition, various goals students pursued in mathematics courses could be identified. Furthermore, for all the aspects mentioned, changes over the course of studying as perceived by students were explored. Beyond this, the attributions students made for their results in mathematics exams and the amount of time they spent studying for mathematics courses could be extracted from the transcripts as well. Overall, the study thus yielded an extensive description of (meta-)cognitive, motivational and behavioral aspects of self-regulated learning of engineering students in mathematics tertiary education.

To summarize, the current dissertation provides important insights into self-regulated learning in mathematics tertiary education in general and that of engineering students in particular. Thus, it provides a valuable foundation for future research and the development of optimal support for students as they make their way through higher education in general and mathematics courses in particular.

Zusammenfassung

Eine hohe Anzahl an Absolventinnen und Absolventen von Ingenieurstudiengängen ist sowohl aus Sicht der einzelnen Studierenden als auch aus ökonomischer und gesellschaftlicher Sicht erstrebenswert. Jedoch sehen sich Ingenieurstudierende während ihres Studiums mit einer Reihe von Herausforderungen konfrontiert, darunter auch Mathematik-Lehrveranstaltungen, die nicht nur in Deutschland ein typischer und oftmals verpflichtender Bestandteil von Ingenieurstudiengängen sind. Viele der Erklärungen für die Schwierigkeiten Studierender in Mathematik-Lehrveranstaltungen können unter dem Oberbegriff des selbstregulierten Lernens zusammengefasst werden. Obwohl die Forschung im Bereich des selbstregulierten Lernens sehr umfangreich ist, weißt sie dennoch entscheidende Lücken auf, welche die Nutzung des entsprechenden Wissens zur Verbesserung der Mathematik-Hochschullehre erschweren. Die vorliegende Dissertation möchte dazu beitragen, diese Lücken zu schließen und den Studienerfolg von (Ingenieur-)Studierenden in der Mathematik-Hochschullehre zu fördern.

In der ersten Studie wurde ein systematisches Review der Forschungsliteratur zum Thema selbstreguliertes Lernen in der Mathematik-Hochschullehre im aktuellen Jahrtausend durchgeführt. Mehrere Datenbanken, die sowohl psychologische als auch mathematische Forschung abdeckten, wurden systematisch durchsucht. Zudem wurden explorative Suchstrategien angewendet. Nach Anwendung eines zweistufigen Selektionsprozesses konnten so 28 relevante Publikationen identifiziert werden. Die Publikationen wurden mit Hilfe eines standardisierten Kategoriensystems kodiert. Dies ermöglichte es, die vorhandene Literatur im Hinblick auf adressierte Forschungsthemen, zugrunde gelegte Theorien, verwendete Definitionen und fokussierte Aspekte von selbstreguliertem Lernen, genutzte Studiendesigns und Messinstrumente sowie Zielgruppen zu beschreiben. Auf dieser Grundlage konnten dann Schlüsse hinsichtlich der Charakteristika und Korrelate von selbstreguliertem Lernen in der Mathematik-Hochschullehre sowie hinsichtlich Möglichkeiten, dieses zu fördern, gezogen werden.

In der zweiten Studie wurden teilstrukturierte Interviews mit Ingenieurstudierenden, die an einer Mathematik-Lehrveranstaltung einer deutschen Technischen Universität teilnahmen, geführt. Die finale Stichprobe beinhaltete 27 Studierende. Die anonymisierten Transkripte wurden deduktiv-induktiv kodiert und ausgewertet. So konnten wichtige (meta-)kognitive und ressourcenbezogene Strategien identifiziert werden, welche die Studierenden in Mathematik-Lehrveranstaltungen nutzten. Für mehrere Lernangebote wurden Gründe für die (Nicht-)Nutzung, Art und Häufigkeit der Nutzung und wahrgenommene Nützlichkeit herausgearbeitet. Zudem konnten verschiedene Ziele der Studierenden in Mathematik-Lehrveranstaltungen identifiziert werden. Für alle genannten Aspekte wurden auch selbstwahrgenommene Veränderungen im Laufe des Studiums erforscht. Darüber hinaus wurden Attributionen für Klausurergebnisse und die aufgewendete Lernzeit für Mathematik-Lehrveranstaltungen herausgearbeitet. Insgesamt ergab die Studie somit eine umfangreiche Beschreibung des selbstregulierten Lernens Ingenieurstudierender in der Mathematik-Hochschullehre in (meta-)kognitiver, motivationaler und behavioraler Hinsicht.

Zusammenfassend bietet die vorliegende Dissertation wichtige Einblicke in selbstreguliertes Lernen im Hochschulkontext im Allgemeinen und dem von Ingenieurstudierenden im Besonderen. Damit bietet sie eine wertvolle Grundlage für weitere Forschung und die Entwicklung von optimalen Unterstützungsmöglichkeiten für Studierende auf ihrem Weg durch ein Hochschulstudium allgemein und Mathematik-Lehrveranstaltungen im Besonderen.

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1. Introduction

Engineering is a sought-after profession. For example, in Germany, vacancies for engineering positions exceed the number of graduates, which is partly due to the fact that many engineers do not work as traditional engineers but instead have other jobs such as professors or managers (Koppel, 2014). Thus, engineers make important contributions to economy. Furthermore, compared to other occupation groups, they receive high salaries and have low rates of temporary employment (Koppel, 2014). A similar situation has been reported from other countries such as the United States of America (U.S.) (National Science Board, 2018). Hence, a high number of students successfully completing an engineering degree program can be considered to be beneficial to individual students as well as to future employers and, in an even broader picture, to a country's economy.

In the light of this, it is problematic that drop-out rates in engineering degree programs are relatively high. For example, Heublein et al. (2017) report a drop-out rate of 32% for engineering degree programs in Germany. Taking a different methological approach, Klöpping et al. (2017) found drop-out rates between 19% and 23% for engineering degree programs at German universities after the prescribed period of study. Freshmen and sophomore year seem to be especially challenging for students (Derboven & Winkler, 2010). For example, Heublein et al. (2017) found that in Germany, 42% of drop-outs of bachelor engineering degree programs occur during the first two semesters, and additional 31% happen during the third and fourth semester. Similarly, Klöpping et al. (2017) report that the majority of changes of institution or degree program and drop-outs of engineering degree programs happens during the first two semesters. Similar findings have been reported from other countries such as the United Kingdom (U.K.) (Baillie & Fitzgerald, 2000) and the U.S. (Marra, Rodgers, Shen, & Bogue, 2012).

One large milestone on the way to success in engineering degree programs appears to be mathematics. Mathematic skills are necessary for all science, technology, engineering and mathematics (STEM) subjects (Dehling, Glasmachers, Griese, Härterich, & Kallweit, 2014; Zimmerman, Moylan, Hudesman, White, & Flugman, 2011) and mathematics is an important tool and language for engineering as a profession (Gainsburg, 2015; Harris et al., 2015). Thus, it seems appropriate that engineering students are required to enroll in a non-trivial number of mathematics courses as part of their studies in Germany (Griese, 2016; Griese, Glasmachers, Härterich, Kallweit, & Roesken, 2011; Härterich et al., 2012; Rooch, Kiss, & Härterich, 2014) but also other countries such as Norway (Rønning, 2014). However, at the same time, these courses appear to be a major obstacle for engineering students (e.g. Dehling et al., 2014; Griese, 2016; Griese, Glasmachers, Härterich, et al., 2011). In Germany, for mathematics courses, failure rates from over 40% (Dehling et al., 2014) up to 70% (Roegner, Heimann, & Seiler, 2016) have been reported. Similar problems have been identified in other countries such as the U.K. (Harris et al., 2015) and Norway (Rønning, 2017). In addition to this, Baillie and Fitzgerald (2000) found that lacking preparation for the level of mathematics required was one reason engineering students gave for dropping out of their degree program. Similarly, Bergsten and Jablonka (2017) report that engineering students cited mathematics as a potential reason for dropping out of their studies. Furthermore, according to a study by van Dyken, Benson, and Gerard (2015), retention in engineering degree programs is significantly predicted by the level of and grade received in mathematics courses taken in the first semester.

In light of this, it seems essential to identify and remedy the causes of engineering students' difficulties with mathematics. Previous respective endeavors have yielded an array of explanations focusing on students as well as on teachers and the educational system, although most of them are not specific to engineering students but rather refer to mathematics tertiary education in general. For example, several researchers have proposed that students' difficulties are at least partly due to their lacking skills concerning time management and organization (e.g. Dehling et al., 2014; Griese, 2016; Griese, Glasmachers, Kallweit, & Rösken, 2011; Roegner et al., 2016). Maladaptive learning strategies (e.g. Griese, 2016; Kürten, Greefrath, Harth, & Pott-Langemeyer, 2014; Roegner et al., 2016; Rooch et al., 2014), respectively changing requirements regarding learning strategies (Rach & Heinze, 2011, 2013) have also been identified repeatedly as (reasons for) difficulties of students in mathematics courses. Furthermore, Roegner et al. (2016) list lacking foundational knowledge, social contacts, realistic self-assessment, and effort concerning tasks as well as too little preparation for and use of learning resources as difficulties of students in mathematics tertiary education. Similarly, Hilgert (2016) described lacking correction of tasks and review of lectures, a missing ability to evaluate one's own learning and concentration problems as some of the (manifold) difficulties of students in mathematics degree programs. And in a study by Kürten et al. (2014), mathematics lecturers identified lacking foundational knowledge and awareness of knowledge gaps as common problems of students and reported that especially struggling students did not make use of existing support services. However, researchers have also identified weaknesses of the learning environment, especially missing linkages of course content with future employment or real-world-applications (e.g. Dehling et al., 2014; Griese, 2016; Griese, Glasmachers, Kallweit, et al., 2011; Harris et al., 2015; Rach & Heinze, 2011; Rooch et al., 2014), too little use of examples and explanations, lacking transparency concerning rating criteria for exams and delayed feedback for students' tasks (Roegner et al., 2016).

Many of the reported explanations that focus on students can be integrated under the umbrella term of self-regulated learning. Self-regulated learning has been intensively researched in educational psychology for more than three decades (Dent & Koenka, 2016; Panadero, 2017). A broad array of self-regulated learning models exists (for a review, see Panadero (2017)). They comprise cognitive, metacognitive, motivational, affective, behavioral and contextual variables, many of which have been found to be related to academic performance (e.g. Credé & Phillips, 2011; Dent & Koenka, 2016; Richardson, Abraham, & Bond, 2012; Robbins et al., 2004; Schneider & Preckel, 2017; but see also Spinath, 2012) and persistence (Robbins et al., 2004). Furthermore, self-regulated learning is considered to be essential for successful lifelong learning (Benz, 2010; Boekaerts, 1999; Cornford, 2002).

Self-regulated learning plays an important role in tertiary education (Spinath & Seifried, 2018), since, compared to school, it is characterized by greater freedom with respect to learning (Pintrich, 2004; Schiefele, Streblow, Ermgassen, & Moschner, 2003). However, this freedom comes along with obligations, since students are expected to manage their academic studies for the most part self-dependently (Wild, 2005) and guidance provided by learning offers is often limited (Schiefele et al., 2003).

This general pattern applies also to mathematics tertiary education (Dehling et al., 2014). It is for example common use for students to receive weekly mathematics problems to be solved independently, respectively with peers (Rach & Heinze, 2011). Preparation for exams is also supported only to a limited extent. Students are expected to spend a lot of time studying for mathematics courses outside of formal learning environments such as lectures (Griese, 2016). Furthermore, the formal learning environments themselves, especially lectures, also provide few opportunities for feedback and support and thus require students to posess (or develop) adequate self-regulated learning skills (Hoops, Yu, Wang, & Hollyer, 2016).

Thus, with the long-term goal of contributing to improving engineering students' success in mathematics courses, the current dissertation focussed on self-regulated learning in mathematics tertiary education. The topic of interest was tackled using two approaches. Firstly, a systematic literature review was conducted to provide an overview on the current state of knowledge concerning self-regulated learning in mathematics tertiary education. Secondly, semi-structured interviews were conducted with engineering students enrolled in a mathematics course at a German university of technology to explore their self-regulated learning in-depth. However, before these studies are described, the following chapter (Chapter 2) first provides an overview on important theories and research in the field of self-regulated learning. Based on this, several open questions, respectively gaps remaining in the existing literature are identified, which the current dissertation aims to address and fill. Then, the systematic review of research on self-regulated learning in mathematics tertiary education (Chapter 3) and the interview study examining engineering students' self-regulated learning in mathematics courses (Chapter 4) are presented. Finally, in Chapter 5, results of both studies are summarized to answer the overarching questions addressed by the dissertation, respectively to fill the identified gaps in the existing literature. Furthermore, general limitations as well as overarching implications for research and practice of the dissertation are summarized and discussed.

2. General Theoretical Background

Intensive research on self-regulated learning dates back over more than 30 years (Dinsmore, Alexander, & Loughlin, 2008; Schmitz, Schmidt, Landmann, & Spiel, 2007; Schunk & Mullen, 2013; Sitzmann & Ely, 2011). During this time, researchers have developed numerous models and definitions of self-regulated learning, which include various and differing cognitive, metacognitive, motivational, affective, behavioral and contextual variables (Dent & Koenka, 2016; Dignath, Buettner, & Langfeldt, 2008; Panadero, 2017; Pintrich, 2000b; Schmitz, Landmann, & Perels, 2007; Sitzmann & Ely, 2011). It is beyond the purpose of the current chapter to provide an exhaustive account of all models and constructs connected to this field of research. Instead, the chapter will present a short overview on those models and constructs with special relevance to the field of self-regulated learning research and the following studies. Where available and appropriate, the reader will be referred to systematic reviews or meta-analyses for more extensive, and detailed summaries of models or empirical research.

The basis for selecting the models presented in the following paragraphs was a recent review by Panadero (2017). According to this review, the most important current models of self-regulated learning are those by Boekaerts and colleagues (e.g. Boekaerts, 1991, 1995, 1996, 1997a, 1997b, 2011; Boekaerts & Cascallar, 2006; Boekaerts & Corno, 2005), Efklides (2011), Hadwin and colleagues (Hadwin, Järvelä, & Miller, 2018; Hadwin, Järvelä, & Miller, 2011; Järvelä & Hadwin, 2013; Miller & Hadwin, 2015), Pintrich (Pintrich, 2000b, 2004; Pintrich & Zusho, 2002), Winne and colleagues (Butler & Winne, 1995; Winne, 1996, 2001, 2010, 2011; Winne & Hadwin, 1998, 2008; Winne & Perry, 2000), and Zimmerman (Schunk & Zimmerman, 1997; Zimmerman, 2000, 2002, 2006, 2011, 2013; Zimmerman & Martinez-Pons, 1990; Zimmerman & Moylan, 2009). Furthermore, Panadero (2017) also pointed to the relevance of further models, namely those of Azevedo and colleagues (Azevedo & Cromley, 2004; Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004; Azevedo & Witherspoon, 2009), Schmitz and colleagues (Schmitz, 2001; Schmitz, Klug, & Schmidt, 2011; Schmitz, Landmann, et al., 2007; Schmitz & Schmidt, 2007; Schmitz & Wiese, 1999; Schmitz & Wiese, 2006) and Wolters (Wolters, 1998, 2003; Wolters, Benzon, & Arroyo-Giner, 2011; Wolters, Pintrich, & Karabenick, 2005). Thus, these nine models will be described shortly in the following section.

Monique Boekaerts developed the six-component model of self-regulated learning, which describes the interaction of a motivational and a (meta-)cognitive regulatory system consisting of different types of prior knowledge at three different levels (Boekaerts, 1996, 1997b). Furthermore, she developed the Adaptable Learning model (Boekaerts, 1991, 1995, 1997a, 1997b), which led to the Dual-Processing Self-Regulation model (Boekaerts & Cascallar, 2006; Boekaerts & Corno, 2005). An important characteristic of the Dual-Processing Self-Regulation model is that it posits that in learning contexts, students have multiple interacting and dynamic goals, which can broadly be clustered into acquiring knowledge and skills versus achieving well-being and positive experiences (Boekaerts, 2011; Boekaerts & Corno, 2005). The two types of goals are connected to two different paths of self-regulated learning. When a situation is appraised as being in line with one's personal learning goals, these goals guide self-regulation processes including cognitive and motivational strategies which lead to the acquisition of knowledge and competences in a top-down process (Boekaerts, 2011; Boekaerts & Corno, 2005). In contrast to this, if based on situational cues students perceive that well-being is in danger, this activates respective goals and a bottom-up process of self-regulation (Boekaerts, 2011; Boekaerts & Cascallar, 2006; Boekaerts & Corno, 2005). Furthermore, according to the model, volitional strategies support the pursuit of learning goals (Boekaerts & Cascallar, 2006; Boekaerts & Corno, 2005). Panadero (2017) provides a more elaborate description of the development of the different models.

Efklides's (2011) metacognitive and affective model of self-regulated learning (i.e. the MASRL model) also distinguishes between a top-down and a bottom-up process of self-regulation. However, these processes are not equivalent in meaning to those defined by Boekarts (e.g. Boekaerts & Corno, 2005) described above (see also Panadero, 2017). The model distinguishes two interacting levels of self-regulated learning. At the Person level general decisions about how to proceed are made before a specific task is approached. These are influenced by stable, interacting (meta-)cognitive, motivational, affective and volitional characteristics as well as general perceptions of the task. The Task x Person level is active when working on a specific task. When decisions made on the Person level are only executed during task-processing, this is defined as a top-down process of self-regulation. However, if changes to such decisions are made during the actual work on the task, this is defined as a bottom-up process of self-regulation (Efklides, 2011).

In the framework designed by Paul Pintrich (Pintrich, 2000b, 2004; Pintrich & Zusho, 2002), four areas of self-regulation (cognition, motivation or affect, behavior, and context) are distinguished. Furthermore, the framework (Pintrich, 2000b, 2004; Pintrich & Zusho, 2002) describes four phases of self-regulated learning. During the phase of forethought, planning and activation, learners try to recall content and metacognitive knowledge and define goals for the task. They adopt achievement goals, judge self-efficacy, task difficulty, task value, and interest as well as experience emotions. They also plan their behavior (e.g., time and effort to be spent) and methods to control it. Moreover, they observe the task and the context (e.g., classroom climate). In the phase of monitoring, learners monitor their cognition (e.g., comprehension), motivation and affect (e.g., anxiety), behavior (e.g., time spent), and the task and context (e.g., course requirements). During the control phase, learners use cognitive learning strategies as well as strategies to control motivation and affect. They regulate their behavior (e.g., by seeking help) and make attempts to control the task and the context (e.g., by changing the study environment). During the phase of reaction and reflection, learners judge their performance as well as the effort and time spent. They experience affective reactions to and make attributions for their performance. Furthermore, they decide upon future behavior and evaluate the task as well as the context (Pintrich, 2000b, 2004; Pintrich & Zusho, 2002). The model allows for learners to be in several phases simultaneously or to return to phases instead of just linearly proceeding through them (Pintrich, 2000b, 2004; Pintrich & Zusho, 2002). In particular, the phases of monitoring and control seem to be interwoven and difficult to separate (Pintrich, 2000b, 2004; Pintrich & Zusho, 2002). Special features of Pintrich's model are the inclusion of the areas of behavior (Efklides, 2011; Panadero, 2017) and context (Sitzmann & Ely, 2011). Furthermore, very well known is also the Motivated Strategies for Learning Questionnaire (MSLQ) developed by Pintrich and his colleagues that covers students' learning strategies and motivation (Pintrich, Smith, Garcia, & McKeachie, 1991, 1993). A review of Pintrich's work can be found in Schunk (2005), a review of the use of the MSLQ (Pintrich et al., 1991) in Duncan and McKeachie (2005) and a meta-analysis of the relationship between the MSLQ (Pintrich et al., 1991) and academic achievement in college in Credé and Phillips (2011).

Winne and Hadwin's model (1998) (see also Butler & Winne, 1995; Winne, 1996, 2010, 2011; Winne & Hadwin, 2008; Winne & Perry, 2000) differs from the other models in that it describes not only separate phases of self-regulated learning but also processes of information processing in these phases (Greene & Azevedo, 2007; Panadero, 2017). Furthermore, it is characterized by the central role that it ascribes to metacognitive monitoring (Butler & Winne, 1995; Greene & Azevedo, 2007; Winne, 2001, 2010; Winne & Perry, 2000). In addition, it is the only model, which defines task definition as a separate phase of self-regulated learning (Greene & Azevedo, 2007). In this first and very important phase, the task is processed and interpreted depending on the learner's domain, task, and strategy knowledge and motivational beliefs as well as depending on environmental task information (Butler & Winne, 1995; Winne, 2001, 2010, 2011; Winne & Hadwin, 1998, 2008; Winne & Perry, 2000). In the following phases, the learner defines personal goals and makes plans to reach them (goal setting and planning phase), sets this plan in action by using tactics and strategies (enactment phase) and lastly and optionally, makes adaptations to perceptions, goals, plans, tactics and strategies for the specific task or even broader adaptations, e.g. to motivation or knowledge (adaptation phase) (Butler & Winne, 1995; Greene & Azevedo, 2007; Winne, 2001, 2010, 2011; Winne & Hadwin, 1998, 2008; Winne & Perry, 2000). Each phase is characterized by interactions between external and internal conditions (i.e. task-related and internal resources and limitations), operations (i.e. cognitive processing of information), products (i.e. cognitive, behavioral or affective results of operations), standards (i.e. definitions of the optimal outcome of phases), and evaluations (i.e. feedback, respectively comparisons of products and standards) (in short, COPES) (Greene & Azevedo, 2007; Winne, 2001, 2010; Winne & Hadwin, 1998, 2008; Winne & Perry, 2000). For a detailed review of the model and the respective empirical evidence, the reader is referred to Greene and Azevedo (2007).

Hadwin and colleagues (Hadwin et al., 2018; Järvelä & Hadwin, 2013; Miller & Hadwin, 2015) proposed an extension to the model of Winne and Hadwin (1998), which differs from the other models presented here mainly in its focus on the social nature of regulated learning. In the model, self-regulated learning is differentiated from co-regulated learning and socially shared regulation of learning. Self-regulated learning is assumed to be necessary but not sufficient when learning in groups (Hadwin et al., 2018; Järvelä & Hadwin, 2013; Miller & Hadwin, 2015). Co-regulation of learning is defined as one or several group member(s) supporting or directing socially shared regulation of learning (Hadwin et al., 2018) or the self-regulation processes of one or several of the other group members (Hadwin et al., 2018; Järvelä & Hadwin, 2013; Miller & Hadwin, 2015). It can be initiated by the receiver and the provider of this support as well as by technological tools (Hadwin et al., 2018). In contrast to this, in socially shared regulation of learning, the group engages in or negotiates regulation processes collaboratively in the pursuit of a shared goal (Hadwin et al., 2018; Hadwin et al., 2011; Järvelä & Hadwin, 2013; Miller & Hadwin, 2015). Furthermore, the model transfers the phases of self-regulated learning as well as the COPES described by Winne and Hadwin (1998) (see above) to the social domain (Hadwin et al., 2018; Miller & Hadwin, 2015). Panadero and Järvelä (2015) reviewed empirical evidence for socially shared regulation of learning.

According to the so-called Cyclical Phases of Self-Regulated Learning model by Zimmerman (Zimmerman, 2000; see also Zimmerman, 2002, 2006, 2011, 2013; Zimmerman & Moylan, 2009), important phases of self-regulated learning are forethought, performance, and self-reflection. In the forethought phase, learners analyze tasks, define goals and plan the use of learning strategies, depending at least partly on their motivational beliefs (e.g., self-efficacy). In the performance phase, learners use self-control processes (e.g., learning strategies) and monitor their performance as well as their environment. In the self-reflection phase, learners make evaluations of and attributions for their performance and react upon it (e.g., by changing their goals) (Zimmerman, 2000, 2002, 2006, 2011, 2013; Zimmerman & Moylan, 2009). Besides this model, which is the one typically associated with him (Panadero, 2017), Zimmerman also developed two other models of self-regulated learning. The Triadic Analysis of Self-Regulated Learning model (Zimmerman, 2000, 2006, 2013; Zimmerman & Martinez-Pons, 1990) specificies the areas of self-regulated learning. People are assumed to self-regulate personal (covert) processes and states, their performance, respectively behavior, and their environment. And the Multi-Level model (Schunk & Zimmerman, 1997; Zimmerman, 2000, 2013) describes the stages in which self-regulated learning skills are acquired. These are: Observing models, repeating the skill displayed by the model with guidance, using the skill in the same context without guidance, and finally, flexibly adapting it to varying internal and external conditions. Lastly, it should be noted that Zimmerman and Martinez Pons (1986) also developed an instrument to assess self-regulated learning strategies, the Self-Regulated Learning Interview Schedule (SRLIS). Zimmerman himself summarized his models and research in a review in (2013), and a review of the Cyclical Phases of Self-Regulated Learning model can be found in Panadero and Alonso-Tapia (2014).

The model of Azevedo and colleagues (Azevedo & Cromley, 2004; Azevedo, Cromley, et al., 2004; Azevedo, Guthrie, et al., 2004; Azevedo & Witherspoon, 2009) is mainly based on the work of Winne and colleagues (Winne & Hadwin, 1998), while also referring to the models of Zimmerman (2000) and Pintrich (2000b) described above. Similar to these models, it includes four phases or main categories of self-regulated learning. The first is called forethought/planning/activation and involves learners setting and remembering (sub-)goals, making plans and trying to remember relevant prior knowledge. Learners' monitoring and regulation of their learning and understanding, the task and the environment with the use of various, more or less effective, strategies as well as their reflections about it, are described in the other three phases or main categories called monitoring, strategy use, and task difficulty and demands (Azevedo & Cromley, 2004; Azevedo, Cromley, et al., 2004; Azevedo, Guthrie, et al., 2004; Azevedo & Witherspoon, 2009). The special characteristics of the model however are the focus on learning in hypermedia contexts (Azevedo & Cromley, 2004; Azevedo, Cromley, et al., 2004; Azevedo, Guthrie, et al., 2004) and micro-level processes (Azevedo & Witherspoon, 2009) as well as the inclusion of context variables such as the behavior of tutors (Azevedo, Cromley, et al., 2004).

Schmitz and colleagues (Schmitz, 2001; Schmitz et al., 2011; Schmitz, Landmann, et al., 2007; Schmitz & Schmidt, 2007; Schmitz & Wiese, 1999; Schmitz & Wiese, 2006) developed their process model of self-regulated learning based on the Cyclical Phases of Self-Regulated Learning model by Zimmerman (2000). The model distinguishes between three components or phases of self-regulated learning. In the preaction phase, learners set goals for a task, influenced by situational and motivational aspects. In the action phase, learners apply (meta-)cognitive, resource management and volitional strategies and thus, spend time learning. In the postaction phase, learners reflect on learning quality and quantity and consequently experience (dis-)satisfaction, which in turn leads to affective reactions and potentially to changes of self-regulated learning, for example, of goals (Schmitz, 2001; Schmitz et al., 2011; Schmitz, Landmann, et al., 2007; Schmitz & Schmidt, 2007; Schmitz & Wiese, 1999; Schmitz

& Wiese, 2006). Two distinctive characteristics of the model according to the authors are the inclusion of volitional strategies as well as the description of self-regulated learning as a series of states, which are defined as learning directed at a specific task during one day and at home (Schmitz et al., 2011; Schmitz, Landmann, et al., 2007; Schmitz & Wiese, 2006).

Finally, the work of Wolters (Wolters, 1998, 2003; Wolters et al., 2011; Wolters et al., 2005) focusses specifically on the regulation of motivation. Wolters not only differentiated motivational regulation from volition and other related constructs and situated it within the context of self-regulated learning in general (Wolters, 2003) and the model of Pintrich (2000b) in particular (Wolters et al., 2011); he also described and studied several specific strategies students might use for regulating their motivation such as self-consequating (Wolters, 1998, 2003; Wolters et al., 2005).

Besides the theoretical models of self-regulated learning presented above, several constructs deserve special attention, since they are important elements in many of these models and stand in the focus of the second study of this dissertation. The following paragraphs will introduce the reader to relevant theories and empirical research concerning learning strategies, achievement goals, and attributions. Again, this chapter can and does not claim to be exhaustive. Instead, where available and appropriate, the reader is referred to meta-analyses and reviews for more in-depth elaborations.

Learning strategies have been researched intensively in the past decades (Wild, 2005, 2006). Rooted in cognitive psychology, one important line of research in the field of learning strategies assumes that learning strategies influence the encoding process of information (Weinstein & Mayer, 1986; Wild, 2006). Typical categories of learning strategies include cognitive strategies, which support the uptake, processing and storing of information, metacognitive strategies, which support control of learning, and resource management strategies, which support and organize learning with the help of internal and external resources (Wild, 2005, 2006; Wild & Schiefele, 1994). Important representatives of this line of research are Weinstein and Mayer (1986), the research group around Pintrich (e.g. Pintrich, 1999; Pintrich & Garcia, 1991; Pintrich et al., 1993) and, for Germany, Wild and Schiefele (1994). The current dissertation (see Chapter 4) builds especially on the work of the latter researchers. Based on the MSLQ (Pintrich et al., 1991), Wild and Schiefele (1994) developed a questionnaire, the so called „Inventar zur Erfassung von Lernstrategien im Studium“ (LIST), to assess students’ use of learning strategies in higher education. More specifically, the questionnaire is supposed to assess cognitive, metacognitive and resource management strategies, which are each further differentiated into more specific learning strategies. As specific cognitive strategies, the instrument assesses a) rehearsal strategies, which support storage of information in long-term memory through repetition, b) elaboration strategies, which support the integration of content into existing knowledge, for example by linking them with personal experiences, c) organizational strategies, which transform content to ease its processing, for example by creating a summary and d) critical checks, i.e. critical and creative thinking. Metacognitive strategies assessed in this questionnaire are planning, self-monitoring and regulation of learning. And concerning resource management strategies, a distinction is made between management of intern (i.e. attention, effort, and time) and extern resources (i.e. peers, additional literature, and the learning environment) (Wild, 2005; Wild & Schiefele, 1994). Several researchers have summarized theories and research on learning strategies (e.g. Wild, 2005) and their relationship to academic achievement (e.g. Credé & Phillips, 2011; Wild, 2005).

Achievement goals are an important motivational construct, which has been researched for over 30 years (Elliot & Murayama, 2008; Kaplan & Maehr, 2007). Although the existing theoretical approaches to classify achievement goals have often been suggested to be similar (Köller & Schiefele, 2006; Urhahne, 2008), more recently, several researchers (Elliot & Murayama, 2008; Grant & Dweck, 2003; Hulleman, Schrager, Bodmann, & Harackiewicz, 2010; Hulleman & Senko, 2010) have stressed the importance of paying closer attention to the conceptualization and measurement of achievement goals. Two important theoretical approaches in the field are the work by Elliot and colleagues (e.g. Elliot & Church, 1997; Elliot & McGregor, 2001; Elliot & Murayama, 2008; Elliot & Thrash, 2001) and the model by Grant and Dweck (2003). The hierarchical model of achievement motivation developed by Elliot and Church (1997) distinguishes between three types of achievement goals. Mastery goals are characterized by a focus on learning, gaining knowledge and understanding (challenging) material. Performance-approach goals are characterized by striving to outperform others and to demonstrate high ability (also compared to others). And performance-avoidance goals are characterized by the goal to avoid poor performance and negative judgements of one's competences by others. In later works, mastery goals were also differentiated into approach and avoidance components, with the latter being characterized by striving to avoid incomplete learning and understanding or loss of skills or abilities (Elliot & McGregor, 2001; Elliot & Murayama, 2008; Elliot & Thrash, 2001). However, the trichotomous model is still a commonly used model (Huang, 2012) and empirical studies show that mastery-avoidance goals have a lower prevalence among university students and do not predict academic performance (Elliot & McGregor, 2001; Elliot & Murayama, 2008). In the model by Grant and Dweck (2003), four achievement goals are distinguished. Learning goals involve a focus on the development of skills, the acquisition of knowledge and abilities, learning and mastering challenges. Normative goals are characterized by a focus on normative standards, and thus, on striving to outperform others and demonstrate superior ability compared to them. Ability goals are described as striving for the demonstration or validation of one's ability. Lastly, outcome goals are characterized by the aim to perform well, as measured for example by good grades. Two relatively recent meta-analyses provide a good overview on varying conceptualisations and measurements of achievement goals as well as their relationship to academic achievement (Huang, 2012; Hulleman et al., 2010). Furthermore, Hulleman and Senko (2010) provide a descriptive summary of research on achievement goals and stress critical issues.

Attributions can be defined as beliefs about the causes of events, in particular events that are important, unexpected or negative (Weiner, 1972, 1979, 1985). They have often been studied in the context of education, however, they also occur also in other contexts such as sports (Weiner, 1979; Whitley & Frieze, 1985). According to attribution research, in achievement situations, typically identified causes include ability, effort, luck, task difficulty, (lack of) support, health, activation, personality, or mood (Graham, 1991; Weiner, 1979, 1985; Weiner, Nierenberg, & Goldstein, 1976). Weiner (Graham, 1991; Weiner, 1979, 1985; Weiner et al., 1976) identified three dimensions along which attributions can be classified. Firstly, students can make attributions to causes internal (e.g. ability or effort) or external (e.g. teacher or task) to them (*locus dimension*). Secondly, causes can be rather stable (e.g. ability) or unstable (e.g. mood) (*stability dimension)*. Thirdly, causes differ concerning the degree, to which they can be controlled volitionally (e.g. effort vs. luck) (*control dimension)*. According to Weiner (1979, 1985), the classification of perceived causes depends on the individuals' perception. Nevertheless, it is common in attribution research to classify causes according to a

2x2x2 matrix resulting from a division of the dimensions into two categories each (Graham, 1991; Weiner, 1979). According to the model by Weiner (Graham, 1991; Weiner, 1972, 1979, 1985; Weiner et al., 1976), attributions influence students' affective reactions and expectancy of success, which in turn affect behavior, and thus, future performance. For example, attributions of failure to stable causes are assumed to lead to a stronger decrease in expected further success and thus, decreased persistence, compared to attributions of failure to unstable causes (Graham, 1991; Weiner, 1972, 1979, 1985). Several meta-analyses and reviews (e.g. Graham, 1991; Hall, French, & Marteau, 2003) have summarized attribution research, with more recent works focusing for example on attributional biases or asymmetries (Malle, 2006; Mezulis, Abramson, Hyde, & Hankin, 2004), academic achievement and retention (Fong et al., 2017), or organizational outcomes (Harvey, Madison, Martinko, Crook, & Crook, 2014).

As the short outline above demonstrated, self-regulated learning is a very intensively researched field with a strong and diverse theoretical basis. At the same time, as outlined in the introduction (see Chapter 1), various explanations have been provided for the difficulties students experience in mathematics courses in tertiary education that match with the assumptions inherent in self-regulated learning theories and the constructs targeted in self-regulated learning research. Thus, at first sight, these different research strands should be merged easily. Yet, existing research in the field of self-regulated learning has several limitations or gaps, which impede a productive synthesis.

Firstly, despite the thematic overlap, to the author's knowledge, research at the intersection of self-regulated learning and mathematics tertiary education has not yet been summarized in a systematic review. Thus, researchers and practitioners interested in this specific topic are left alone to discover for themselves, what previous research can tell them about the nature and correlates of self-regulated learning in mathematics tertiary education, or about possibilities to support it. Furthermore, when designing their own research, interventions, courses etc. they are faced with many questions and decisions, for example concerning the theories to build their work on or the instruments to assess self-regulated learning with. Although exploring previous research independently can certainly produce satisfactory results and is a natural element in the life of researchers, it still bears many risks. Especially researchers and practitioners new to the field might find the richness and diversity of the existing literature confusing and hard to overlook (e.g. Dinsmore et al., 2008; Pintrich, 2004; Wild, 2005) and become discouraged. Furthermore, the risk for repeating the work (and mistakes) of others, as well as for overlooking "blind spots" that are under-researched is non-trivial. The current dissertation addresses the questions described above (as well as many more) by providing a systematic review of research on self-regulated learning in mathematics tertiary education since the year 2000 (see Chapter 3) and thus, fills a large gap in the literature.

Secondly, research regarding self-regulated learning has mostly been conducted in North America (Pintrich, 2000b). This applies also to the constructs especially relevant to the current dissertation, that is, to research on learning strategies (Credé & Phillips, 2011), achievement goals (Huang, 2012; Hulleman et al., 2010) and attributions (Mezulis et al., 2004). However, there exist many differences between Germany and North America, for example regarding the educational system (e.g. Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010). For instance, in the U.S., students often decide upon a major when entering college but real specialization happens only during the two last years (Hilgert, 2016; Marra et al., 2012). In contrast to this, in Germany, students enroll directly in specific degree programs.

Beyond education, other important differences can be identified as well, for example regarding engineering culture (Downey & Lucena, 2004). Moreover, there is empirical evidence, which can nurture doubts about the global applicability of results of self-regulated learning research. For example, recent meta-analyses have identified the nationality or culture of students, respectively the sample as a significant moderator of associations among achievement goals and between achievement goals and academic achievement (Huang, 2012; Hulleman et al., 2010) as well as of the strength of attributional biases (Mezulis et al., 2004). Thus, researchers and practitioners working in Germany are faced with the question, to what extent existing research in the field of self-regulated learning can be transferred to the situation and students they encounter at German institutions of higher education, or even more generally, how self-regulated learning is characterized in this particular environment and population.

In a similar vein, thirdly, for self-regulated learning in general and the constructs described above in particular, research conducted in mathematics tertiary education contexts is not extensive and very rare for engineering students in particular (e.g. Roth, Ogrin, & Schmitz, 2016; Schmitz & Wiese, 2006). This will also become obvious in the following chapters describing the systematic review of respective research (see Chapter 3) and the theoretical background of the interview study (see section 4.1). At the same time, again, both theoretical considerations as well as empirical evidence exist that contest the applicability of results of self-regulated learning research regardless of the situation in which they were retrieved. In particular, previous research has found evidence for context-dependency of learning strategies (e.g. Dent & Koenka, 2016; Greene et al., 2015; Liebendörfer et al., 2014; Rotgans & Schmidt, 2009), achievement goals (e.g. Bong, 2001; Sparfeldt, Buch, Wirthwein, & Rost, 2007), and attributions (e.g. Boekaerts, Otten, & Voeten, 2003). Furthermore, many important theorists have stressed the importance of the context for self-regulated learning (e.g. Boekaerts, 1995; Schunk, 2005; Schunk & Zimmerman, 1997; Zimmerman, 2000). Thus, researchers and practitioners interested in mathematics tertiary education are faced with the question, whether insights derived from existing research can actually be applied to their specific situations of interest.

The current dissertation will try to provide an initial answer to these questions by exploring (meta-)cognitive, motivational, and behavioral aspects of self-regulated learning in the context of mathematics tertiary education in a sample of engineering students of a German university of technology (see Chapter 4). Thus, it enriches existing research in the field of self-regulated learning by providing a rare perspective on a specific domain, respectively context, and country. Beyond this, also the systematic review (see Chapter 3) can contribute to answering these questions. It provides an overview on self-regulated learning research specific to the context of mathematics tertiary education and explicitly broaches the issue of the countries in which respective research has been conducted.

Fourthly and lastly, although several researchers have proposed that qualitative methods are appropriate to investigate self-regulated learning (Hoops et al., 2016; Montalvo & Torres, 2004), numerous reviews (Dinsmore et al., 2008; Moos & Ringdal, 2012; Roth et al., 2016; Spörer & Brunstein, 2006), including the review presented in the current dissertation (see Chapter 3) found that self-regulated learning research is strongly based on questionnaires. However, self-report measures in general and Likert-scale questionnaires in particular (e.g. Boekaerts & Corno, 2005; Dent & Koenka, 2016; Spörer & Brunstein, 2006; Winne, 2010) have been criticized in various respects and have several limitations. For example, questionnaires are relatively inflexible as they provide students with preset questions (Spörer & Brunstein, 2006). In addition, as outlined above, existing questionnaires such as the MSLQ (Pintrich et al., 1991) were often developed by important theorists in the field of self-regulated learning and are thus connected to their theoretical approach. Thus, researchers and practicioners interested in self-regulated learning in a specific context, such as mathematics education for engineering students, need to consider, whether questionnaires (and the results of studies using them) can adequately represent students' reality. Furthermore, for researchers interested in using alternative methods to assess self-regulated learning, it is difficult to find previous studies, which could provide orientation.

The current dissertation tackles these challenges in two respects. On the one hand, the systematic review (see Chapter 3) will not only provide an overview on the findings of previous research on self-regulated learning in mathematics tertiary education, but will also describe and discuss the study designs and instruments used by the reviewed studies. On the other hand, in the empirical study (see Chapter 4), semi-structured interviews were chosen as the main means of data collection. On the one hand, this method allows to pre-structure the interview based on existing knowledge and thus, to recognize the state of theory and research, but on the other hand it still provides students with the opportunity to give answers that are unexpected from the researcher's point of view and which could not have been anticipated based on theoretical considerations in advance of the study (Roth et al., 2016; Spörer, 2003). In addition, as compared to questionnaires, it can be more safely assumed that students actually use the strategies they report (Spörer & Brunstein, 2006).

Based on this short introduction to relevant theories and constructs of self-regulated learning and the remaining open questions and gaps in the literature, the following two subsections will present the studies, which constitute the main body of this dissertation. The systematic review is described first (Chapter 3), since it continues and deepens the elaboration of existing literature begun in the current chapter, with a special focus on research on self-regulated learning in mathematics tertiary education since the year 2000. Following this, the reader should have gained a sufficient understanding of the research field in order to be introduced to the empirical study (Chapter 4), in which semi-structured interviews were conducted with engineering students regarding their self-regulated learning in mathematics courses at a German university of technology. Lastly, the general discussion (Chapter 5) will bring together the two studies, focusing in particular on their contribution to answering the overarching questions and filling the existing gaps in the literature outlined above. Furthermore, this final chapter will discuss general implications of the findings of the dissertation for research and practice as well as general limitations of the dissertation, and round it off with some concluding remarks.

3. The current state of research on self-regulated learning in mathematics tertiary education: A systematic review

Self-regulated learning is an area of intensive interdisciplinary research (Boekaerts, 1999; Dent & Koenka, 2016; Panadero, 2017; Schunk & Mullen, 2013), which is characterized by a broad variety of theoretical models (Dignath & Büttner, 2008). Due to this richness and diversity, existing literature on self-regulated learning is hard to overlook and, especially for practitioners and researchers new to the field, sometimes confusing and ambiguous (e.g. Dinsmore et al., 2008; Pintrich, 2004; Wild, 2005). In order to find a remedy for this situation, the current study will provide an overview on the current state of research on self-regulated learning in mathematics tertiary education. In line with Zeidner, Boekaerts, and Pintrich (2000), self-regulated learning is understood as involving cognitive, metacognitive, motivational, affective and behavioral aspects.

3.1. Theoretical Background

Over the last decades, numerous researchers have made attempts to summarize research on self-regulated learning. Systematic reviews and meta-analyses have covered research on self-regulated learning in specific contexts, such as online (Adam, Alzahri, Cik Soh, Abu Bakar, & Mohamad Kamal, 2017; Artino, 2008; Broadbent & Poon, 2015; Tsai, Shen, & Fan, 2013), computer-based (Devolder, Van Braak, & Tondeur, 2012; Winters, Greene, & Costich, 2008; Zheng, 2016) or problem-based (Loyens, Magda, & Rikers, 2008) learning environments as well as in physical education (Kolovelonis & Goudas, 2013) and higher education and the workplace (Sitzmann & Ely, 2011). There also is a review on research conducted with pre- or inservice teachers (Moos & Ringdal, 2012). Furthermore, numerous systematic reviews and meta-analyses have summarized research on self-regulated learning related training programs or interventions and their effects (Benz, 2010), some focusing on specific populations, such as primary school students (Dignath et al., 2008), secondary school students (Dignath & Büttner, 2008), students with emotional and behavioral disorders (Popham, Counts, Ryan, & Katsiyannis, 2018) or students and professionals in the medical sector (Brydges et al., 2015). In addition, measurement instruments and methods (Dinsmore et al., 2008; Roth et al., 2016) and definitions (Dinsmore et al., 2008) of self-regulated learning, as well as terms used in research on regulation in collaborative and cooperative learning (Schoor, Narciss, & Körndle, 2015) have been in the focus of systematic reviews as well. Beyond this, several meta-analyses have examined the role of self-regulated learning in predicting academic achievement, for example in specific contexts, such as online learning environments (Broadbent & Poon, 2015) or for specific groups, such as students in elementary and secondary school (Dent & Koenka, 2016) or higher education (Credé & Phillips, 2011; Fong et al., 2017; Richardson et al., 2012; Robbins et al., 2004), as well as in predicting retention (Fong et al., 2017; Robbins et al., 2004). Furthermore, there exist a systematic review on the relationship between self-regulated learning and homework (Ramdass & Zimmerman, 2011) as well as a meta-analysis on the relationship between self-regulated learning and personal epistemology (Alpaslan, Yalvac, & Willson, 2017).

In addition, non-systematic reviews have provided overviews on (specific aspects of) self-regulated learning research (e.g. Boekaerts & Cascallar, 2006; Stone, 2000; Zeidner et al., 2000), including models and conceptualisations (e.g. Boekaerts & Corno, 2005; Panadero, 2017; Puustinen & Pulkkinen, 2001; Schunk & Mullen, 2013), assessment methods (e.g.

Boekaerts & Corno, 2005; Montalvo & Torres, 2004; Panadero, Klug, & Järvelä, 2016; Schunk & Mullen, 2013; Spörer & Brunstein, 2006; Winne & Perry, 2000; Wirth & Leutner, 2008), and interventions (e.g. Boekaerts & Corno, 2005; Montalvo & Torres, 2004). Furthermore, as mentioned earlier, some reviews have focused on specific models of self-regulated learning (Greene & Azevedo, 2007; Schunk, 2005; Zimmerman, 2013).

To summarize, it can be clearly seen, that other researchers have also felt the need to summarize self-regulated learning research. Most relevant to the current study is the work of Adam et al. (2017), who shortly covered the topic of mathematics in a review of self-regulated learning research, pointing in particular to the process of problem-solving and the work of De Corte, Verschaffel, and Op't Eynde (2000), who (non-systematically) summarized research results concerning several aspects of students' self-regulation in mathematics as well as concerning interventions to improve self-regulated learning in mathematics. However, to the author's knowledge, to date, no systematic review has been conducted which summarizes research on self-regulated learning in mathematics tertiary education since the year 2000. The current study aims to fill this gap and thus, to contribute to the development of the research field as well as to the dissemination of its findings into practice.

3.2. Research questions

The current study addressed the following research questions:

1. What is the current state of research regarding self-regulated learning in mathematics tertiary education?
    a. Which topics have been addressed?
    b. Which theories have framed research?
    c. How has self-regulated learning been defined?
    d. Which research designs have been used?
    e. Which measurement instruments have been used?
    f. Which target groups have been studied?
2. What can this research tell us about the nature and correlates of self-regulated learning in mathematics tertiary education?
3. What can this research tell us about possibilities to support self-regulated learning in mathematics tertiary education?

Thus, the current review included three steps of insight. In a first step, relevant studies were systematically summarized regarding key aspects. Based on this, in a second step, it was explored, which overarching conclusions could be drawn from the existing literature regarding the nature of self-regulated learning in mathematics tertiary education and related constructs. In a third step, possibilities for supporting self-regulated learning that were supported by the existing research were identified.

3.3. Method

The systematic literature review was conducted in several stages. The method chosen was developed based on general recommendations for systematic reviews (Liberati et al., 2009) and methods applied in other reviews, in particular those by Halverson, Graham, Spring, Drysdale, and Henrie (2014) and Drysdale, Graham, Spring, and Halverson (2013). The process is depicted in Figure 1 and described in more detail below.

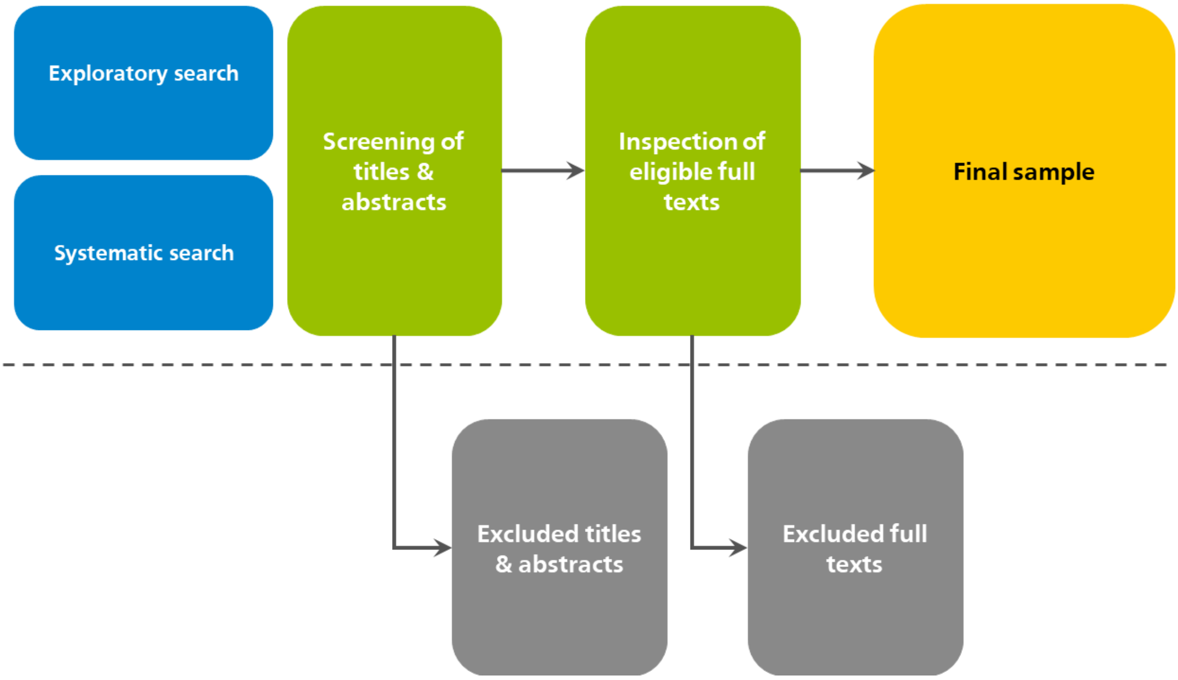

Figure 1. Process of the systematic literature review.

3.3.1. Literature search

Articles were searched using a systematic approach. Firstly, the outcome measure was defined as all studies investigating self-regulated learning in the context of mathematics tertiary education. Based on this definition, English and German search terms were specificied, which can be found in Table 1. Secondly, these search terms were used to search six databases. ERIC and PsychInfo are important, reliable and high-quality databases for the field of educational psychology (Greene & Azevedo, 2007) and Psyndex is suited to search for German psychological research (Dignath et al., 2008). In addition, the Zentralblatt MATH and the Mathematics Education Database were searched because they include research from the field of mathematics in general, respectively from mathematics education research (Universitätsbibliothek Regensburg, n.d.). Lastly, Web of Science was included as a database because it covers a broad area of disciplines (Universitätsbibliothek Regensburg, n.d.). All potential combinations were included in one search per database using Boolean/Phrase search. Depending on the database, pre-set filters were applied to reduce the number of records to be screened. The resulting records were imported into a citation manager. Titles and abstracts were read and filtered according to criteria specified in advance. In case of doubt, articles were retained through the first filtering stage and read in full.

Table 1

Aspects of the outcome measure and related search terms defined for the systematic review

Aspect of outcome measure	Search term
Self-regulated learning	Self-regulation; self-regulated learning; Selbstregulation; selbstreguliertes Lernen
Educational level	Tertiary education; higher education; university; college; postsecondary; post-secondary; Hochschule; Hochschullehre; Universität
Educational context	Mathematics; mathematic; math; maths; Mathematik; Mathe; mathematisch

The following eligibility criteria were applied:

1) *At least one of the search terms concerning self-regulated learning is included in the title or abstract*. This restriction was implemented due to the fuzziness of the construct of self-regulated learning, which is an umbrella term for a broad variety of variables (Panadero, 2017). Including all studies examining variables associated somehow with self-regulated learning would have weakened the focus of the review, which aimed at capturing only those studies with a strong focus on self-regulated learning. Furthermore, lack of limitation of papers to those including the term "self-regulated learning" in the title or abstract yielded unsatisfactory results in a previous review (Dinsmore et al., 2008): It led to the identification of studies referring to self-regulated learning only peripherally in the theoretical background or discussion.
2) *A common model of self-regulated learning is used as a basis for research and/or argumentation.* Again, this restriction was implemented to ensure that the review included only studies with a clear focus on self-regulated learning, as it is understood in the research community. The definition of common models was based on the review of Panadero (2017) and included the models described in Chapter 2. Furthermore, studies using established measures of self-regulated learning developed based on these models (see also Chapter 2 and the review of Panadero (2017)) fulfilled this criterion as well. Publications in which the title and abstract contained no hints concerning the models or instruments used as basis for research and/or argumentation were retained through the first stage of filtering and judged based on the full text.
3) *The study was conducted in the context of higher education.* This restriction was implemented due to the focus of the current review. Studies examining preparatory courses for university studies held at institutions of higher education fulfilled this criterion, whereas studies in which university entrance tests were the latest point of measurement were excluded. If publications reported multiple studies, of which only some fulfilled the fourth criterion concerning mathematics education (see below), the higher education criterion was applied only to the latter studies.

4) *The study was conducted in the context of mathematics education.* This restriction also reflected the focus of the current review. Studies in which mathematical knowledge or performance were assessed (e.g. in experiments containing mathematical tasks) fulfilled this criterion. However, if studies were clearly conducted in another context and the abstract and title did not provide evidence that mathematics performance and self-regulated learning were studied in relation to each other, they were excluded.
5) *The article is written in German or English*. This restriction was implemented since the author of this dissertation could not ensure that texts published in other languages would be read with adequate skill.
6) *The article is published between 2000 and 2018.* This restriction was implemented since the review was supposed to describe the current state of research.
7) *The article is published in a peer-reviewed journal*. This restriction was implemented to ensure the quality of the articles included in the review. Editor-reviewed journals were excluded, as well as conference articles, dissertations and other publications not fulfilling this criterion.
8) *The article is no duplicate*. If articles were included in several databases, they were retained through the first stage of filtering and read in full text only once.

Thirdly, all articles, which were deemed (potentially) relevant and which were not excluded based on the criteria described above, were obtained and read in full text. They were again filtered based on the criteria mentioned above. Fourthly, exploratory searches were conducted. For all relevant articles identified through the systematic database search, the articles they cited (rolling snowball method) as well as the articles, which cited them (cited reference search in Web of Science) were determined. Records were retrieved with the help of student assistants and subjected to the same two-tier screening procedure as the records obtained through the database searches.

3.3.2. Coding of information

From the articles included in the final sample, information was extracted by the author of this dissertation. A standardized coding sheet was used to improve coding quality (Credé, Roch, & Kieszczynka, 2010). Where possible, as described below, categories were defined in advance and were based on other reviews or important theoretical contributions. The full coding sheet can be found in appendix 7.1. However, relevant categories and analyses will be explained in the following to ensure the adequate interpretation of the respective results.

In order to answer research question 1a, oriented on similar procedures by Halverson et al. (2014) and Drysdale et al. (2013), all research questions and hypotheses of the reviewed articles were identified. They were coded with the software MAXQDA 2018 using an inductive coding method based on the suggestions of Kuckartz (2016). The following steps were taken to analyze the data:

1) All research questions and hypotheses were read and spontaneously generated thematic categories were assigned to those with relevance to self-regulated learning according to the interpretations of the author(s).
2) All generated categories were reviewed and organized, i.e. where appropriate, categories with similar meanings were aggregated and/or organized hierarchically,

meaning that more specific categories were subsumed under a common category of higher order, which was developed at this stage.
3) The results of this analysis were documented in a category system, in which all categories were listed and defined (see appendix 7.2).
4) All research questions and hypotheses and their position in the category system were again reviewed and where necessary, adaptations were made to the category system or the coding of the research questions and hypotheses. Where necessary, the full texts were considered.

For research question 1b, based on the review by Panadero (2017), it was coded and analyzed, whether the articles included in the review referred to models by the following researchers or research groups: Azevedo and colleagues (Azevedo, Guthrie, et al., 2004), Boekaerts and colleagues (Boekaerts, 1991, 1996; Boekaerts & Corno, 2005), Efklides (2011), Hadwin and colleagues (Hadwin et al., 2018), Pintrich (Pintrich, 2000b; Pintrich et al., 1991), Schmitz and colleagues (Schmitz & Wiese, 2006), Winne and colleagues (Winne & Hadwin, 1998), Wolters (2003), and Zimmerman (Zimmerman, 1989, 2000; Zimmerman & Martinez Pons, 1986). If prominent instruments were referred to, this was coded as well. Please note that here and in the following, for the sake of readability and consistency, only one major publication will be cited for each specific model, respectively instrument. This does not imply that it was always this exact publication that was referred to in the reviewed studies. A description of the models and further relevant publications can be found in Chapter 2. For each theory relevant for an article, it was also coded whether it had been “explicitly stated” (i.e. the author(s) had explicitly mentioned that they built on the theory), “cited” (i.e. the author(s) had made references to the theory) or been inferred from the “measurement” (i.e. the measurement used belonged to a specific research tradition and no other category applied). Furthermore, where appropriate, it was also coded, which specific theoretical model was referred to. The judgements were made based on the description of the author(s) and the review by Panadero (2017). Furthermore, if necessary, the publications cited were read.

In order to answer research question 1c, modeled after similar procedures used by Dinsmore et al. (2008) and Murphy and Alexander (2000), it was coded how the author(s) had defined self-regulated learning. Definitions were coded as explicit, if the author(s) explicitly gave a personal definition of self-regulated learning or explicitly stated that a particular theoretical framework, definition etc. was adopted. If a definition did not fulfil these criteria, it was coded as implicit. In this case, a further distinction was made between “conceptual” (i.e. the author(s) elaborated on the concept, possibly citing works of various other researchers, but neither appropriating nor highlighting a specific definition or theoretical framework); “referential” (i.e. the author(s) referred to the work of specific other researchers but did not elaborate on it); “conceptual & referential” (i.e. the author(s) referred to works of specific other researchers and elaborated on it) or “measurement” (i.e. the measurement provided the only information on how self-regulated learning was defined). Furthermore, it was coded on which aspects of self-regulated learning the study focussed. In alignment with several other researchers (Benz, 2010; Dignath & Büttner, 2008; Panadero, 2017; Zeidner et al., 2000) and the definition of self-regulated learning, which was adopted for the current review, the following aspects were coded: Cognitive, metacognitive, motivational, affective, and behavioral. The specific constructs on which the study focussed were coded as well. The decision, what aspect a certain construct represented was made based on the description of the author(s). If no respective information was available, the author of this dissertation based her judgement on the framework by Pintrich (2004).

With respect to research question 1d, the research designs applied in the reviewed studies were coded. Categories and coding rules were based on the dimension and classification criteria of research designs described by Döring and Bortz (2016). Regarding the data basis of the studies, it was coded whether data were first collected and analyzed ("primary study") or not originally collected but re-analyzed ("secondary study") for the reviewed study or if the reviewed study summarized results from previous studies in a "meta-analysis". Depending on how research groups were treated and built (i.e. the experimental design), studies were further coded as an "experimental study" if they randomly assigned participants to groups and systematically manipulated the independent variable(s), as a "quasi-experimental study" if the condition of random assignment was not fulfilled, or as a "non-experimental study" if both conditions were not fulfilled. Furthermore, it was coded whether the study was conducted in a controllable ("laboratory study") or natural, less controllable ("field study") environment. The last category referring to the research design was the number of measurement points. For (quasi-)experimental studies, it was differentiated whether they had several measurement points and/or subjected the same participants to several experimental or control treatments ("repeated measures or within-subjects design") or not ("independent measures or between-subjects design"). For non-experimental studies, "cross-sectional studies" which assessed one sample once with a measurement instrument or did not investigate changes or temporal developments were distinguished from "trend studies", which investigated changes or temporal developments by conducting several cross-sectional studies using different samples but the same measurement instrument, and "longitudinal studies" in which changes or temporal developments were investigated using the same measurement instruments in the same sample at multiple occasions. With respect to experimental design, place of study and number of measurement points, if multiple categories applied to one study, the category with the best fit for the majority of research questions and analyses was selected.

With respect to research question 1e, the measurement instruments used in the reviewed studies to assess self-regulated learning were coded. A priori, the following main types of instruments were differentiated and coded based on previous reviews (Boekaerts & Corno, 2005; Winne & Perry, 2000): Questionnaire, observation, interview, think aloud, diary, traces, test, and judgment of others. Furthermore, for each category, the specific instrument used was coded. Where appropriate, commonly used instruments were defined a priori based on other reviews (Boekaerts & Corno, 2005; Moos & Ringdal, 2012; Panadero, 2017; Roth et al., 2016; Spörer & Brunstein, 2006). In addition, oriented on a meta-analysis by Dent and Koenka (2016), each instrument was judged as "established" (i.e. it occurred in the predefined selection of measurement instruments, even if it was adapted or combined with other instruments), "non-established" (i.e. it was not self-constructed but did not fulfil the criteria for "established") or "self-constructed". For "established" and "non-established" instruments, it was also coded if the author(s) had adapted the instruments, for example by rephrasing items or using only subscales of a questionnaire. In addition, for all instruments, inspired by a similar approach of Dinsmore et al. (2008), it was also coded how well they aligned with the theory or theories framing research and the definitions of self-regulated learning provided by the author(s). The category "full alignment" indicated that the measurement instrument(s) stemmed from the same research tradition as the theory/theories framing research and/or aligned well with the definition of self-regulated learning provided. The category "partial alignment" indicated that the measurement instrument aligned with one of several theories framing research, that one of the measurement instruments aligned with the theory framing research and/or that the measurement instrument(s) only partially aligned with the definition of self-regulated learning provided. "Ill alignment" indicated lacking alignment between measument instrument(s) and both theory/theories and the definition of self-regulated learning provided.

For research question 1f, information regarding the target group of the reviewed studies was coded. Most information was coded openly. In line with Roth et al. (2016), the sample size was further classified as small ($N < 100$), medium ($100 \geq N \leq 400$) or large ($N > 400$). And in line with Dent and Koenka (2016) it was coded, whether the institution of higher education was public or private. Also, in line with the latter meta-analysis, concerning the age of the participants not only the mean, but also the range and the median were coded if respective information was available. If more than one sample was used in a study for separate analyses on purpose or due to the design, information was coded separately for these samples.

3.4. Results

As can be seen from Figure 2, overall, 1333 abstract and titles were screened. From these, 204 articles were retained through the first stage of filtering and read in full text. Three additional articles could not be retrieved in full text and were thus excluded from further analysis, even though they successfully passed the first stage of filtering. Among the articles read in full text, 28 articles fulfilled all criteria and thus were selected for the final sample.

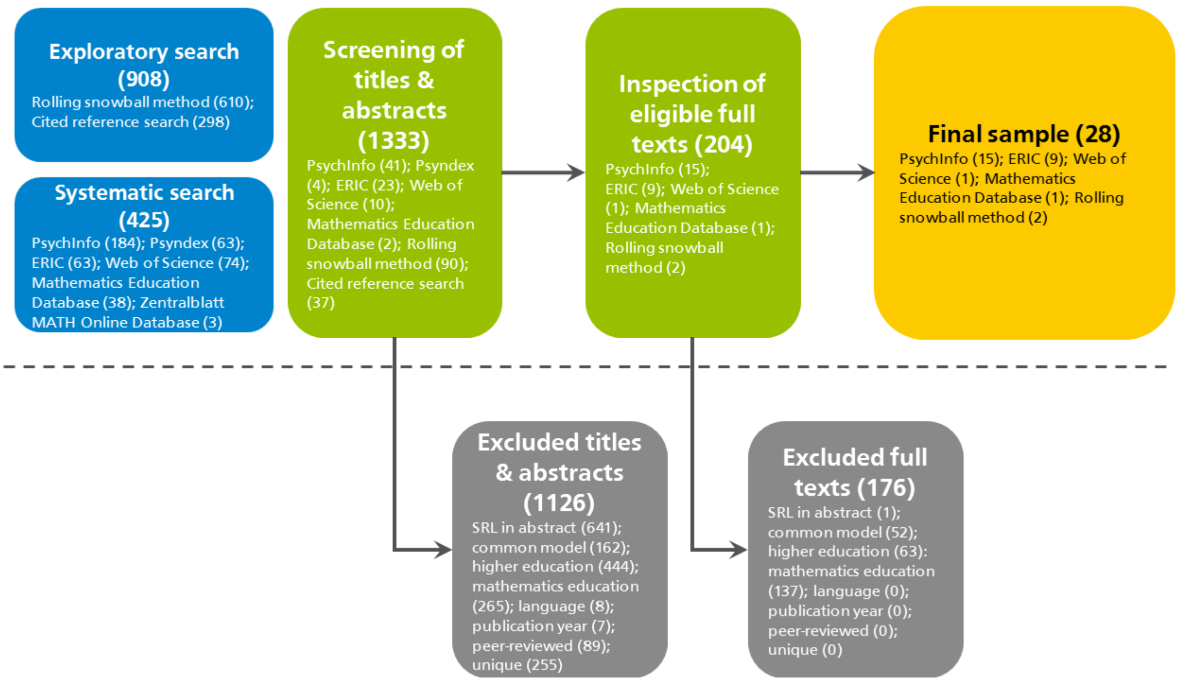

Figure 2. Selection process. Depicted are the overall number of articles identified with different search strategies and the number of hits per source (blue rectangles), the number of articles screened at each stage of the process and the number of articles retained per source (green rectangles); the number of articles included in the final sample and their sources (yellow rectangle), and the number of excluded articles and the reasons for exclusion (grey rectangles).

As can be seen in Figure 3, the articles included in this review were published between 2005 and 2018, with a gap in 2006 (i.e. no articles included in the review were published in 2006) and a peak in 2016 (i.e. five of the 28 included articles were published in 2016).

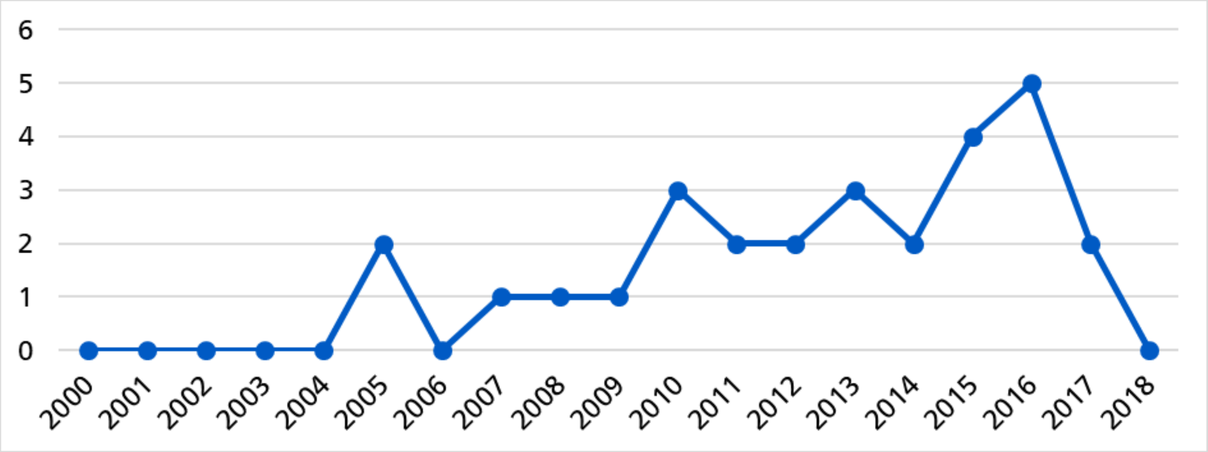

Figure 3. Number of articles included in the final sample of the review per year of publication.

In the following, the results will be presented in order of the research questions addressed in the current study.

3.4.1. **Current state of research**

In order to answer research question 1a, the research questions and hypotheses of the reviewed studies were analyzed to discover, which topics or questions had been addressed. Table 2 shows the results of the inductive coding process. As can be seen, the most frequently addressed topics were the relationship between self-regulated learning, respectively socially shared regulation of learning and mathematics achievement, and effects of self-regulated learning related trainings or interventions. For the latter aspect, subcategories could be created which differentiated between effects on a) self-regulated learning related knowledge and behavior (addressed in seven studies), b) mathematics achievement (addressed in five studies) or c) other variables, which were not subsumed under self-regulated learning by the author(s) (addressed in two studies).

Furthermore, Figure 4 demonstrates the number of published articles per topic over time, i.e. when subdividing the timespan covered by the review into three shorter periods of five (respectively four) years. This visualization demonstrates that some topics were especially relevant during particular phases, for example, that the associations between self-regulated learning and mathematics achievement were intensively studied between 2010 and 2014, whereas during the last years, research on this topic was surmounted by research addressing effects of self-regulated learning related trainings and interventions as well as research targeting phases and temporal sequences of self-, co- and socially shared regulation of learning.

Table 2

Topics addressed according to research questions and hypotheses

Category	*n*	Article
Effects of SRL-related trainings & interventions	9	Acee and Weinstein (2010); Bellhäuser, Lösch, Winter, and Schmitz (2016); Bol, Campbell, Perez, and Yen (2016); Davaanyam and Tserendorj (2015); Hauk (2005); Hodges and Kim (2010); Hudesman et al. (2014); Talbert (2015); Zimmerman et al. (2011)
Association between SRL / SSRL & mathematics achievement	9	Cho and Heron (2015); Fong, Zientek, Yetkiner Ozel, and Phelps (2015); Hodges and Kim (2010); Husman and Hilpert (2007); Loong (2012); Muis (2008); Schoor and Bannert (2012); Villavicencio and Bernardo (2013); Zientek, Yetkiner Ozel, Fong, and Griffin (2013)
Association between SRL & other variables	7	Cho and Heron (2015); Cifarelli, Goodson-Espy, and Chae (2010); Dunn (2014); Husman and Hilpert (2007); Muis (2008); Villavicencio and Bernardo (2013, 2016)
Domain & context dependency of SRL	4	Järvelä, Järvenoja, Malmberg, Isohätälä, and Sobocinski (2016); Rotgans and Schmidt (2009); Sobocinski, Malmberg, and Järvelä (2017); Winne and Muis (2011)
Ethnic & cultural differences concerning SRL / SSRL	3	Fong et al. (2015); Loong (2012); Shi, Frederiksen, and Muis (2013)
Phases & temporal sequences of SRL / CORL / SSRL	7	Hadwin, Wozney, and Pontin (2005); Hodges and Kim (2010); Järvelä et al. (2016); Malmberg, Järvelä, and Järvenoja (2017); Schoor and Bannert (2012); Sobocinski et al. (2017); Talbert (2015)
Other - SRL related	2	Hoops et al. (2016); Winne and Muis (2011)

Note. CORL = co-regulated learning; SRL = self-regulated learning; SSRL = socially shared regulation of learning.

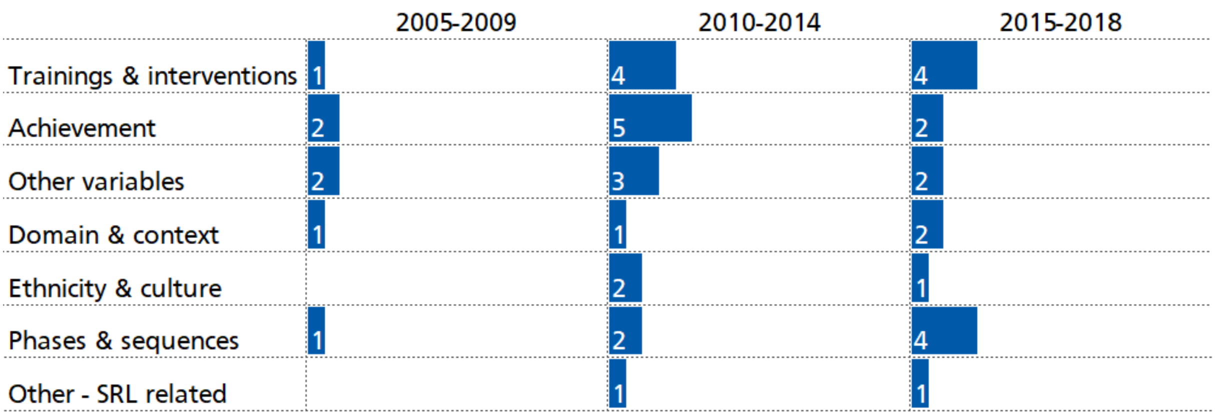

Figure 4. Number of reviewed articles per topic addressed according to research questions and hypotheses in the phases 2005 to 2009, 2010 to 2014 and 2015 to 2018.

Table 3

Theories used as basis for research and/or argumentation

Theory	*n*	Article
Azevedo et al. (Azevedo, Guthrie, et al., 2004)	2	Shi et al. (2013); Sobocinski et al. (2017)
Boekaerts et al.	4	
Six-component model of SRL (Boekaerts, 1996)	1	Schoor and Bannert (2012)
Adaptable Learning model (Boekaerts, 1991)	1	Hauk (2005)
Dual Processing SR Model (Boekaerts & Corno, 2005)	2	Cho and Heron (2015); Villavicencio and Bernardo (2013)
Efklides (2011)	0	
Hadwin et al. (Hadwin et al., 2018)	3	Järvelä et al. (2016); Malmberg et al. (2017); Sobocinski et al. (2017)
Pintrich	16	
Framework (Pintrich, 2000b)	6	Acee and Weinstein (2010); Cho and Heron (2015); Fong et al. (2015); Hoops et al. (2016); Talbert (2015); Villavicencio and Bernardo (2016)
MSLQ (Pintrich et al., 1991)	10	Bellhäuser et al. (2016); Bol et al. (2016); Davaanyam and Tserendorj (2015); Dunn (2014); Hodges and Kim (2010); Husman and Hilpert (2007); Järvelä et al. (2016); Muis (2008); Rotgans and Schmidt (2009); Villavicencio and Bernardo (2013)
Schmitz et al. (Schmitz & Wiese, 2006)	1	Bellhäuser et al. (2016)
Winne et al. (Winne & Hadwin, 1998)	11	Cho and Heron (2015); Hadwin et al. (2005); Hoops et al. (2016); Järvelä et al. (2016); Malmberg et al. (2017); Muis (2008); Schoor and Bannert (2012); Sobocinski et al. (2017); Winne and Muis (2011); Zientek et al. (2013); Zimmerman et al. (2011)
Wolters (2003)	2	Acee and Weinstein (2010); Hoops et al. (2016)
Zimmerman	18	
Cyclical Phases of SRL model (Zimmerman, 2000)	13	Acee and Weinstein (2010); Bol et al. (2016); Cho and Heron (2015); Cifarelli et al. (2010); Fong et al. (2015); Hoops et al. (2016); Hudesman et al. (2014); Järvelä et al. (2016); Malmberg et al. (2017); Schoor and Bannert (2012); Shi et al. (2013); Sobocinski et al. (2017); Zimmerman et al. (2011)
Triadic Analysis of SRL model (Zimmerman, 1989)	6	Cifarelli et al. (2010); Hadwin et al. (2005); Hodges and Kim (2010); Hoops et al. (2016); Loong (2012); Rotgans and Schmidt (2009)
Multi-Level model of SRL (Zimmerman, 2000)	1	Hadwin et al. (2005)
SRLIS (Zimmerman & Martinez Pons, 1986)	1	Zientek et al. (2013)

Note. MSLQ = Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991); SR = self-regulation; SRL = self-regulated learning; SRLIS = Self-Regulated Learning Interview Schedule (Zimmerman & Martinez Pons, 1986).

Research question 1b explored, which theories had framed research. The results of the respective analysis are shown in Table 3 (for more detailed results, see Table 18 in appendix 7.3). Overall, works of Zimmerman (in particular the Cyclical Phases of Self-Regulated Learning model (Zimmerman, 2000)), Pintrich (in particular the MSLQ (Pintrich et al., 1991)) and the model by Winne and Hadwin (1998) were most often used as a frame or basis of research and/or argumentation. The theoretical supremay of this triade can also be observed when further segregating the timespan into three periods of approximately five years (see Figure 5). Beyond this, as can be seen from Table 3, most articles integrated more than one theory. When counting them at the most superficial level (i.e. not differentiating between different models or instruments by the same (group of) researchers), four studies referred to four theories, three studies to three theories, 11 studies to two theories and 10 studies to only one theory. Furthermore, as Table 18 in the appendix 7.3 demonstrates, theories were most often cited and only in the case of the MSLQ (Pintrich et al., 1991) did a measurement instrument provide the only connection to a theoretical framework.

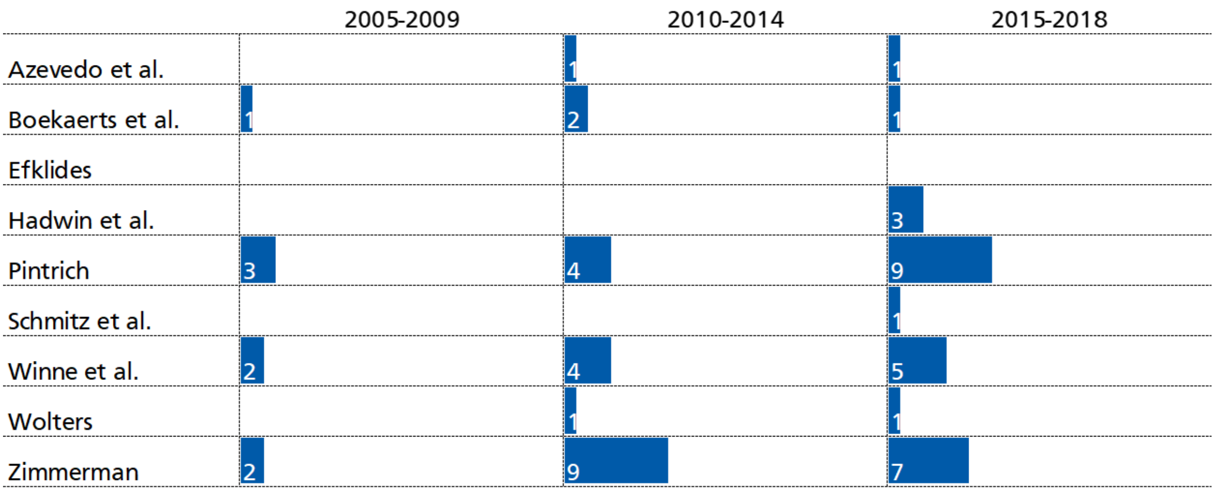

Figure 5. Number of articles per theory used as basis for research and/or argumentation in the phases 2005 to 2009, 2010 to 2014 and 2015 to 2018.

Research question 1c referred to the definitions of self-regulated learning. As outlined in the methods section (see section 3.3.2) definitions were coded as explicit if a personal definition of self-regulated learning was given or if a particular theoretical framework was explicitly appropriated. If the article elaborated on characteristics of self-regulated learning but did not highlight a specific theoretical framework, this was coded as a conceptual definition. In contrast, if particular theories were elaborated, this was coded as a conceptual and referential definition and if references to the work of other researchers were made but not elaborated upon, as a referential definition. Lastly, if no other category applied and the measurement instrument used thus provided the only hint about which theory (potentially) guided research, this was coded as a measurement definition. Exemplary hypothetical phrases which could indicate each type of definition can be found in Table 4.

As can be seen from Table 4, explicit and implicit definitions were observed equally frequent. Among the implicit definitions, the clear majority were conceptual or conceptual and referential definitions. Yet, a slightly different picture emerged when further zooming into the timespan covered by the review (see Figure 6). The number of explicit definitions showed a strong increase over time, whereas conceptual and conceptual and referential definitions were relatively constantly used over time (although the latter only since 2010).

Table 4

Definition types used for self-regulated learning

Definition type	Exemplary phrase	*n*	Article
Explicit	"We defined self-regulated learning as..."; "the theoretical model XY guided our study"	14	Bellhäuser et al. (2016); Cho and Heron (2015); Cifarelli et al. (2010); Davaanyam and Tserendorj (2015); Hadwin et al. (2005); Hoops et al. (2016); Hudesman et al. (2014); Järvelä et al. (2016); Malmberg et al. (2017); Muis (2008); Schoor and Bannert (2012); Shi et al. (2013); Sobocinski et al. (2017); Zimmerman et al. (2011)
Implicit		14	
Conceptual	"Self-regulated learners are characterized by..."; "self-regulated learning includes..."	7	Dunn (2014); Fong et al. (2015); Hauk (2005); Husman and Hilpert (2007); Rotgans and Schmidt (2009); Villavicencio and Bernardo (2016); Winne and Muis (2011)
Conceptual & Referential	"According to the model by XY, self-regulated learning is characterized as ..."; "the model by XY claims that self-regulated learning is..."	5	Acee and Weinstein (2010); Bol et al. (2016); Hodges and Kim (2010); Talbert (2015); Zientek et al. (2013)
Measurement	"Self-regulated learning was measured with the questionnaire XY""	0	
Referential	"XY define self-regulated learning as ..."	2	Loong (2012); Villavicencio and Bernardo (2013)

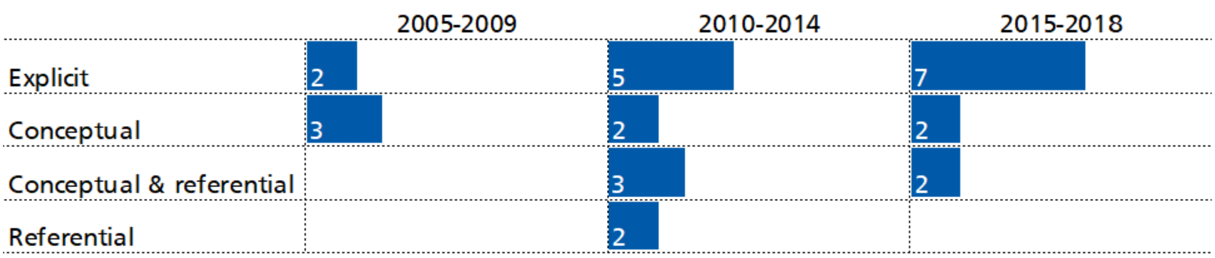

Figure 6. Number of articles per definition types used for self-regulated learning in the phases 2005 to 2009, 2010 to 2014 and 2015 to 2018.

Table 5

Aspects of self-regulated learning addressed

Aspect	Exemplary aspect	*n*	Article
Cognitive	Elaboration subscale of the MSLQ (Pintrich et al., 1991)	12	Bellhäuser et al. (2016); Cho and Heron (2015); Cifarelli et al. (2010); Davaanyam and Tserendorj (2015); Hadwin et al. (2005); Hoops et al. (2016); Järvelä et al. (2016); Loong (2012); Malmberg et al. (2017); Rotgans and Schmidt (2009); Shi et al. (2013); Sobocinski et al. (2017)
Metacognitive	Metacognitive Self-Regulation subscale of the MSLQ (Pintrich et al., 1991)	23	Bellhäuser et al. (2016); Bol et al. (2016); Cho and Heron (2015); Cifarelli et al. (2010); Davaanyam and Tserendorj (2015); Dunn (2014); Hadwin et al. (2005); Hauk (2005); Hodges and Kim (2010); Hoops et al. (2016); Hudesman et al. (2014); Järvelä et al. (2016); Loong (2012); Malmberg et al. (2017); Muis (2008); Rotgans and Schmidt (2009); Schoor and Bannert (2012); Shi et al. (2013); Sobocinski et al. (2017); Villavicencio and Bernardo (2013); Villavicencio and Bernardo (2016); Winne and Muis (2011); Zimmerman et al. (2011)
Motivational	Self-efficacy for Learning and Performance subscale of the MSLQ (Pintrich et al., 1991)	13	Acee and Weinstein (2010); Bellhäuser et al. (2016); Cho and Heron (2015); Hadwin et al. (2005); Hauk (2005); Hoops et al. (2016); Järvelä et al. (2016); Loong (2012); Rotgans and Schmidt (2009); Schoor and Bannert (2012); Shi et al. (2013); Sobocinski et al. (2017); Zimmerman et al. (2011)
Affective	Test Anxiety subscale of the MSLQ (Pintrich et al., 1991)	7	Cho and Heron (2015); Hauk (2005); Hoops et al. (2016); Järvelä et al. (2016); Loong (2012); Rotgans and Schmidt (2009); Shi et al. (2013)
Behavioral	Time and Study Environment subscale of the MSLQ (Pintrich et al., 1991)	14	Bellhäuser et al. (2016); Davaanyam and Tserendorj (2015); Dunn (2014); Hadwin et al. (2005); Hodges and Kim (2010); Hoops et al. (2016); Husman and Hilpert (2007); Järvelä et al. (2016); Loong (2012); Malmberg et al. (2017); Rotgans and Schmidt (2009); Shi et al. (2013); Sobocinski et al. (2017); Talbert (2015)

Note. MSLQ = Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991).

Table 5 and Figure 7 demonstrate, on which aspects of self-regulated learning the studies focussed. It can clearly be seen that metacognitive aspects were of most interest throughout the whole time covered by the review. Cognitive and behavioral aspects experienced a small surge in interest during the last four years. Affective aspects were targeted by the fewest studies. Furthermore, it can be seen from Table 5 that the majority of studies (n=17) focussed on more than one aspect. Five studies focussed on all five aspects, four studies on four aspects, three studies on three aspects, five studies on two aspects and nine studies on one aspect. For two studies (Fong et al., 2015; Zientek et al., 2013), no ratings could be made due to lacking information, in particular regarding the measurement instrument used.

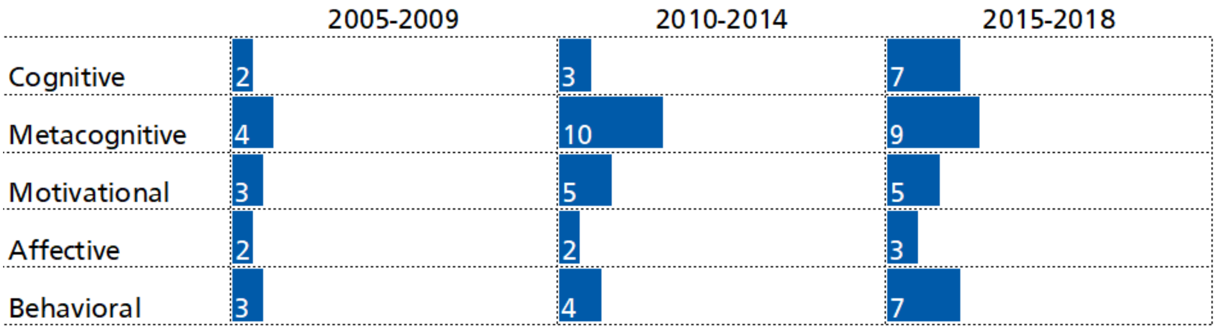

Figure 7. Number of articles per aspect of self-regulated learning addressed in the phases 2005 to 2009, 2010 to 2014 and 2015 to 2018.

In order to answer research question 1d, the research designs of the reviewed studies were analyzed and categorized. Only one study (Schoor & Bannert, 2012) reported that it re-analyzed data from another study and thus, had conducted a secondary analysis. All other studies included primary analyses according to the information provided by the authors. However, it needs to be noted that in some cases, in particular Villavicencio and Bernardo (2013, 2016) as well as Järvelä et al. (2016), Malmberg et al. (2017) and Sobocinski et al. (2017), based on the very similar setting of the studies, the matching sample sizes and descriptions and the overlapping authors, some doubts remained whether the data these studies analyzed had actually been collected and first analyzed for each of the studies. But, since the authors did not indicate that they had re-analyzed the data, these studies were still coded as primary analyses. Furthermore, the great majority (n = 20) studies were classified as field studies. Six studies were conducted in a laboratory setting (Acee & Weinstein, 2010; Järvelä et al., 2016; Malmberg et al., 2017; Schoor & Bannert, 2012; Shi et al., 2013; Sobocinski et al., 2017). For two studies, not enough information was available to categorize them as either field or laboratory studies (Muis, 2008; Winne & Muis, 2011).

As can be seen from Table 6, cross-sectional studies held the biggest share among the reviewed studies. However, almost half of the studies had several measurement points and among them, non-experimental and experimental studies were equally frequent. Only one study (Hudesman et al., 2014) was classified as having a quasi-experimental design. Beyond this, also for the type of experimental design and number of measurement points (see Figure 8) as well as the settings (see Figure 9) which were used by the reviewed studies, a more detailed analysis was conducted, segregating the timespan covered by the review into three shorter phases. Results showed that cross-sectional studies and longitudinal studies were conducted throughout the whole time covered by the review, whereas (quasi-)experimental studies were especially well-represented in the time between 2010 and 2014. Similarly, laboratory studies were also first observed in this period of time.

Table 6

Experimental design and number of measurement points of the reviewed studies

Experimental design & measurement points	*n*	Article
Non-experimental study	18	
Cross-sectional study	12	Cho and Heron (2015); Cifarelli et al. (2010); Dunn (2014); Fong et al. (2015); Hauk (2005); Hoops et al. (2016); Loong (2012); Muis (2008); Rotgans and Schmidt (2009); Villavicencio and Bernardo (2013); Villavicencio and Bernardo (2016); Zientek et al. (2013)
Longitudinal study	6	Hadwin et al. (2005); Husman and Hilpert (2007); Malmberg et al. (2017); Schoor and Bannert (2012); Sobocinski et al. (2017); Talbert (2015)
Trend study	0	
(Quasi-)experimental study	10	
Independent measures or between-subjects design	3	Bol et al. (2016)[1]; Davaanyam and Tserendorj (2015)[1]; Shi et al. (2013)[1]
Repeated measures or within-subjects design	7	Acee and Weinstein (2010)[1]; Bellhäuser et al. (2016)[1]; Hodges and Kim (2010)[1]; Hudesman et al. (2014)[2]; Järvelä et al. (2016)[1]; Winne and Muis (2011)[1]; Zimmerman et al. (2011)[1]

Note. 1 = experimental study; 2 = quasi-experimental study.

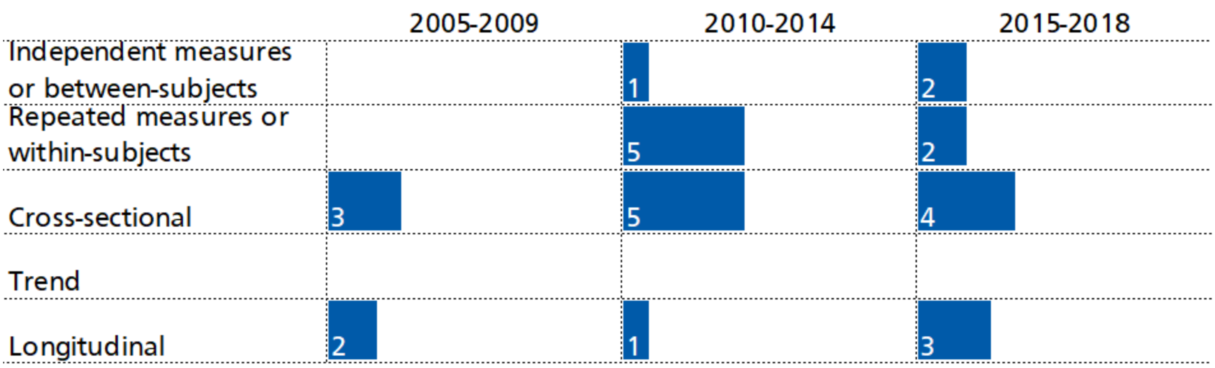

Figure 8. Number of articles per experimental design and number of measurement points used in the phases 2005 to 2009, 2010 to 2014 and 2015 to 2018.

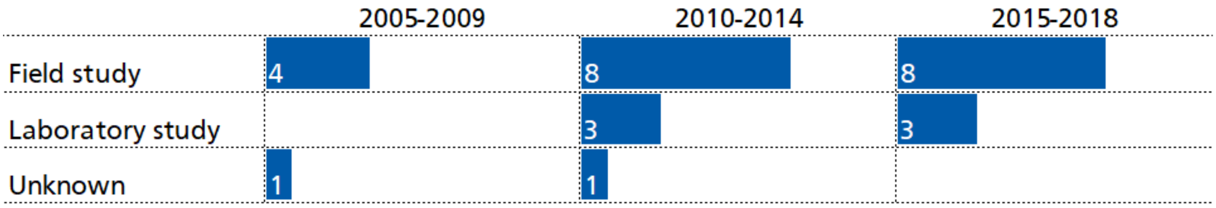

Figure 9. Number of articles per setting used in the phases 2005 to 2009, 2010 to 2014 and 2015 to 2018.

Research question 1e referred to the measurement instruments, which had been used in the reviewed studies to assess self-regulated learning. The results of the respective coding process are summarized in Table 7. As can be seen, questionnaires, in particular adaptations of the MSLQ (Pintrich et al., 1991) were the most frequently used instruments by far. Students' confidence concerning the correctness of test answers (Winne & Muis, 2011; Zimmerman et al., 2011) and their self-efficacy concerning tasks as well as their self-reflection (Zimmerman et al., 2011) were assessed with self-constructed questionnaires. Observations included recording self-regulated learning related practices of instructors (Hoops et al., 2016), students work on mathematics problems or other mathematics-related tasks (Cifarelli et al., 2010; Järvelä et al., 2016; Malmberg et al., 2017; Shi et al., 2013; Sobocinski et al., 2017) and discussions between students and an instructor (Hadwin et al., 2005). Bellhäuser et al. (2016) assessed ratings of self-regulated learning with a diary and declarative knowledge of self-regulated learning with a test. Traces collected included the logfiles of a chat and an editor in an online learning environment (Schoor & Bannert, 2012), students' writings accrued while they worked on mathematics problems (Cifarelli et al., 2010) and mathematical autobiographical essays (Hauk, 2005). The latter author also conducted interviews with former participants of a mathematics course concerning their experiences in the course and their mathematics autobiographical essays. Lastly, Muis (2008) and Cifarelli et al. (2010) used think-aloud procedures during mathematics problem solving.

Furthermore, as can also be inferred from Table 7, the great majority of studies (n=22) used only one instrument type to assess self-regulated learning. However, two studies used two types of instruments and further two studies even used three types of instruments. Furthermore, Acee and Weinstein (2010) and Hudesman et al. (2014) did not assess self-regulated learning at all with an instrument, but self-regulated learning was part of interventions these articles described. Moreover, from Figure 10, it can be seen that although questionnaires were the most often used instrument type over the whole time period covered by the review, especially in the last years, observations were also frequently used in research on self-regulated learning in tertiary mathematics education.

For half of the studies (n=14), alignment between measurement of self-regulated learning and the theories framing research was judged as good ("full alignment"). For eight studies (Bol et al., 2016; Davaanyam & Tserendorj, 2015; Dunn, 2014; Hauk, 2005; Rotgans & Schmidt, 2009; Shi et al., 2013; Talbert, 2015; Villavicencio & Bernardo, 2013), partial alignment was found and for four studies, alignment had to be judged as ill (Fong et al., 2015; Hodges & Kim, 2010; Loong, 2012; Zientek et al., 2013). For two studies, no judgement could be made, because self-regulated learning was part of the intervention but not measured (Acee & Weinstein, 2010; Hudesman et al., 2014).

Table 7

Instrument types used to assess self-regulated learning

Instrument	*n*	Article
Questionnaire	17	Bellhäuser et al. (2016)[1]; Bol et al. (2016) [1]; Cho and Heron (2015) [1]; Davaanyam and Tserendorj (2015)[3]; Dunn (2014) [1]; Fong et al. (2015)[4]; Hodges and Kim (2010) [1]; Husman and Hilpert (2007) [1]; Loong (2012)[2]; Muis (2008) [1]; Rotgans and Schmidt (2009) [1]; Talbert (2015) [1]; Villavicencio and Bernardo (2013) [1]; Villavicencio and Bernardo (2016) [1]; Winne and Muis (2011)[5]; Zientek et al. (2013)[4]; Zimmerman et al. (2011)[5]
Observation	7	Cifarelli et al. (2010) [5]; Hadwin et al. (2005) [5]; Hoops et al. (2016) [5]; Järvelä et al. (2016) [5]; Malmberg et al. (2017) [5]; Shi et al. (2013) [5]; Sobocinski et al. (2017) [5]
Interview	1	Hauk (2005) [5]
Think-aloud	2	Cifarelli et al. (2010) [5]; Muis (2008) [5]
Diary	1	Bellhäuser et al. (2016) [5]
Traces	3	Cifarelli et al. (2010) [5]; Hauk (2005) [5]; Schoor and Bannert (2012) [5]
Test	1	Bellhäuser et al. (2016) [5]
Judgement of others	0	

Note. 1= adapted Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991); 2 = Learning and Study Strategies Inventory (Weinstein, 1988); 3 = adapted Mathematics Motivated Strategies for Learning Questionnaire (as cited in Davaanyam and Tserendorj (2015)); 4 = self-efficacy for self-regulated learning subscale (Marat, 2005); 5 = self-constructed instrument

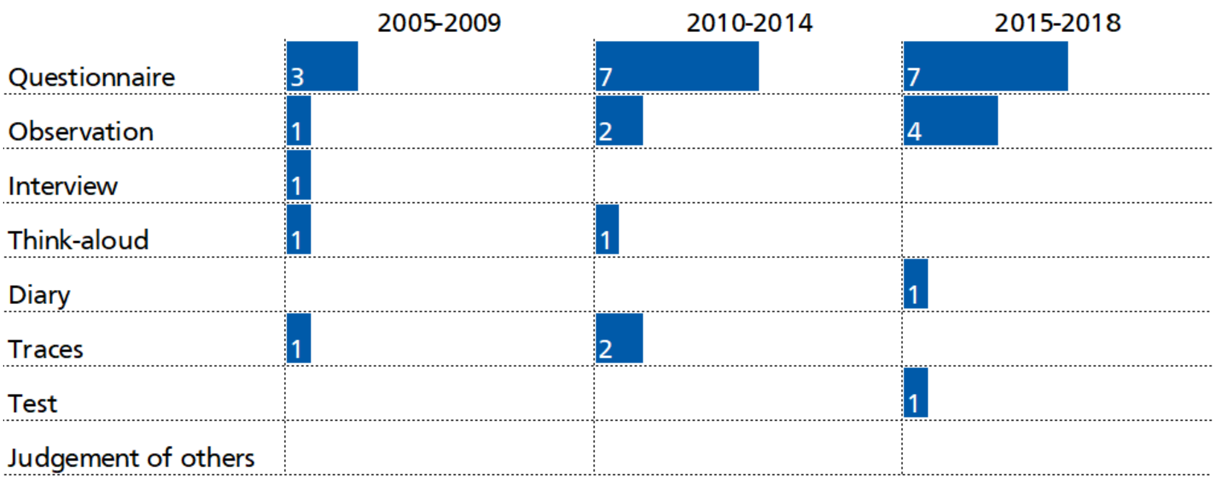

Figure 10. Number of articles per instrument type used to assess self-regulated learning in the phases 2005 to 2009, 2010 to 2014 and 2015 to 2018.

Research question 1f referred to the target groups, which had been studied. Table 8 shows in which countries research was conducted. It can clearly be seen that research was strongly based in North America, however, other countries were represented as well.

Table 8

Countries where research was conducted

Country	*n*	Article
Canada	4	Hadwin et al. (2005); Muis (2008); Shi et al. (2013); Winne and Muis (2011)
Finland	3	Järvelä et al. (2016); Malmberg et al. (2017); Sobocinski et al. (2017)
Germany	2	Bellhäuser et al. (2016); Schoor and Bannert (2012)
Malaysia	1	Loong (2012)
Mongolia	1	Davaanyam and Tserendorj (2015)
Philippines	2	Villavicencio and Bernardo (2013); Villavicencio and Bernardo (2016)
Singapore	1	Rotgans and Schmidt (2009)
U.S.	13	Acee and Weinstein (2010); Bol et al. (2016); Cifarelli et al. (2010); Dunn (2014); Fong et al. (2015); Hauk (2005); Hodges and Kim (2010); Hoops et al. (2016); Hudesman et al. (2014); Husman and Hilpert (2007); Talbert (2015); Zientek et al. (2013); Zimmerman et al. (2011)
Unknown	1	Cho and Heron (2015)

Note. U.S. = United States of America

Table 9

Size of samples used

Sample size	*n*	Article
Large ($N > 400$)	6	Fong et al. (2015); Hoops et al. (2016); Husman and Hilpert (2007); Villavicencio and Bernardo (2013); Villavicencio and Bernardo (2016); Zimmerman et al. (2011)
Medium ($100 \leq N \geq 400$)	13	Bellhäuser et al. (2016); Bol et al. (2016); Cho and Heron (2015); Cifarelli et al. (2010); Davaanyam and Tserendorj (2015); Dunn (2014); Hodges and Kim (2010); Hudesman et al. (2014); Loong (2012); Muis (2008); Rotgans and Schmidt (2009); Winne and Muis (2011); Zientek et al. (2013)
Small ($N < 100$)	12	Acee and Weinstein (2010); Bellhäuser et al. (2016); Cifarelli et al. (2010); Hadwin et al. (2005); Hauk (2005); Järvelä et al. (2016); Malmberg et al. (2017); Muis (2008); Schoor and Bannert (2012); Shi et al. (2013); Sobocinski et al. (2017); Talbert (2015)

Note. Articles were counted only once per category (even if using several samples).

As can be seen from Table 9, the majority of studies used samples of up to 400 students. It needs to be noted that the numbers do not add up to 28 since six studies (Acee & Weinstein, 2010; Bellhäuser et al., 2016; Cifarelli et al., 2010; Hauk, 2005; Muis, 2008; Talbert, 2015) used more than one sample.

Two studies had been conducted at private (Hauk, 2005; Loong, 2012) and 11 at public universities (Acee & Weinstein, 2010; Bol et al., 2016; Fong et al., 2015; Hodges & Kim, 2010; Hoops et al., 2016; Hudesman et al., 2014; Talbert, 2015; Villavicencio & Bernardo, 2013, 2016; Zientek et al., 2013; Zimmerman et al., 2011). For the remaining 15 studies, institution type could not be determined.

The gender ratio for the samples used in the reviewed studies varied broadly from an all-female sample (Hadwin et al., 2005) to an all-male sample (Shi et al., 2013). The majority of samples however was largely female, as can be seen in seen in Table 10.

Table 10

Gender ratio in samples studied

Gender ratio	*n*	Article
<40 % males	14	Acee and Weinstein (2010); Cho and Heron (2015); Davaanyam and Tserendorj (2015); Dunn (2014); Hadwin et al. (2005); Hauk (2005); Hodges and Kim (2010); Järvelä et al. (2016); Malmberg et al. (2017); Muis (2008); Schoor and Bannert (2012); Sobocinski et al. (2017); Winne and Muis (2011); Zientek et al. (2013);
40% -60% males	5	Bol et al. (2016); Cifarelli et al. (2010); Husman and Hilpert (2007); Loong (2012); Zimmerman et al. (2011)
>60% males	5	Bellhäuser et al. (2016); Muis (2008); Shi et al. (2013); Villavicencio and Bernardo (2013); Villavicencio and Bernardo (2016)
Unknown	6	Acee and Weinstein (2010); Fong et al. (2015); Hoops et al. (2016); Hudesman et al. (2014); Rotgans and Schmidt (2009); Talbert (2015)

Note. Articles were counted only once per category (even if using several samples).

Students in the samples were enrolled in various degree programs. Over all, four studies were classified as using at least one mixed sample (Acee & Weinstein, 2010; Hauk, 2005; Schoor & Bannert, 2012; Shi et al., 2013), two definitly used at least one sample of students from non-STEM degree programs (Cifarelli et al., 2010; Rotgans & Schmidt, 2009) and four definitly used at least one sample with students from STEM degree programs (Bellhäuser et al., 2016; Muis, 2008; Talbert, 2015; Villavicencio & Bernardo, 2016). For all other samples, no judgement could be made.

Concerning students' year in college, the most well-represent group were freshmen. However, studies focussed on all levels of higher education, from prospective students to graduate students (see Table 11).

Table 11

Representation of students in samples based on their year in college

Year in college	*n*	Article
Prospective students	2	Bellhäuser et al. (2016); Loong (2012)
1st year / freshmen	10	Acee and Weinstein (2010); Cho and Heron (2015); Cifarelli et al. (2010); Davaanyam and Tserendorj (2015); Hodges and Kim (2010); Husman and Hilpert (2007); Muis (2008); Rotgans and Schmidt (2009); Schoor and Bannert (2012); Villavicencio and Bernardo (2013)
2nd year / sophomores	9	Acee and Weinstein (2010); Cho and Heron (2015); Cifarelli et al. (2010); Hodges and Kim (2010); Järvelä et al. (2016); Malmberg et al. (2017); Muis (2008); Schoor and Bannert (2012); Talbert (2015)
3rd year / juniors	6	Acee and Weinstein (2010); Cho and Heron (2015); Cifarelli et al. (2010); Hodges and Kim (2010); Muis (2008); Schoor and Bannert (2012)
4th year / seniors	6	Acee and Weinstein (2010); Cho and Heron (2015); Cifarelli et al. (2010); Hodges and Kim (2010); Muis (2008); Schoor and Bannert (2012)
Graduate students	5	Acee and Weinstein (2010); Dunn (2014); Hadwin et al. (2005); Muis (2008); Winne and Muis (2011)

Note. Articles were counted only once per category (even if using several samples).

Information on students' age was difficult to analyze due to the varying information the authors provided. Students average age was reported by half of the studies reviewed for at least one sample and ranged from 16.49 (Villavicencio & Bernardo, 2013, 2016) to 33 (Dunn, 2014). In four studies, students average age was below 20 (Hodges & Kim, 2010; Rotgans & Schmidt, 2009; Villavicencio & Bernardo, 2013, 2016), whereas in the other studies reporting this information, it ranged between 20 and 25 (Acee & Weinstein, 2010; Bellhäuser et al., 2016; Cho & Heron, 2015; Järvelä et al., 2016; Malmberg et al., 2017; Muis, 2008; Schoor & Bannert, 2012; Shi et al., 2013; Sobocinski et al., 2017), except for Dunn (2014). No study provided information regarding the median age. Only eight studies reported an age range, which comprised 11 years or less for four studies (Fong et al., 2015; Loong, 2012; Villavicencio & Bernardo, 2013, 2016), but more than 30 years in the other four studies (Bol et al., 2016; Dunn, 2014; Muis, 2008; Zientek et al., 2013).

Similarly, it was difficult to conduct an analysis regarding students' ethnicity. Only 15 studies provided such information but in very different formats. The only real difference, which could be detected was whether white, respectively European American, Caucasian or Caucasian American students held the majority of the sample. In seven studies (Acee & Weinstein, 2010; Cho & Heron, 2015; Cifarelli et al., 2010; Fong et al., 2015; Hauk, 2005; Husman & Hilpert, 2007; Zientek et al., 2013) these students held the majority, whereas in one study, they were a minority (Bol et al., 2016). Shi et al. (2013) had parity between Canadian and Chinese students. Six studies providing information on students' ethnicity could not be categorized according to this schema (Loong, 2012; Rotgans & Schmidt, 2009; Villavicencio & Bernardo, 2013, 2016; Winne & Muis, 2011; Zimmerman et al., 2011).

Building on the foundation of the analyses presented up to now and the understanding of the strengths and weaknesses, respectively the informative value, of the single studies established based on them, in the following two sections, an attempt was made to outline, how the reviewed studies can contribute to our understanding of a) the nature and correlates of self-regulated learning in mathematics tertiary education (research question 2) and b) possibilities to support self-regulated learning in mathematics tertiary education (research question 3). It should be noted that throughout the following sections, the classification of effects as small, medium, or large was made according to the suggestions of Cohen (1992).

3.4.2. Nature and correlates of self-regulated learning

In order to answer research question 2, the reviewed studies were searched for overarching conclusions regarding the nature and correlates of self-regulated learning in mathematics tertiary education. First hints were provided by the analysis described in the previous section concerning the topics addressed in the reviewed studies (see Table 2). Yet, in contrast to the latter analysis, in the following sections, *all* results presented in the reviewed studies were considered, including those not directly inferrable from the research questions or hypotheses. Regarding the further structure of this section, it should be noted that most studies were relevant at various points. To avoid redundancies and to improve the readability of the section, the studies will however be described in detail only at first mention.

3.4.2.1. Nature of self-regulated learning

Several of the reviewed studies focused strongly on describing aspects, phases or the temporal development of self-regulated learning. Assembled, their findings did allow to draw some overarching conclusions. Yet, it needs to be kept in mind that the studies reviewed differed in many important aspects such as students' characteristics, time span observed, measurement instruments and more (see section 3.4.1) and thus, can be integrated only cautiously.

The reviewed studies provide support for conceptualizing self-regulated learning as a process with different phases and (recurring) loops or chains of activities, which, at least in the context of group work, occur with differing frequency. For instance, in a mathematics didactics course in which students worked collaboratively to assemble a didactic concept, performance phases indicated by (monitoring) strategy use, and managing time and study environment were most frequently observed, followed by forethought phases characterized by task-related beliefs and interest, attempts to understand the task, goal setting and planning activities, whereas evaluations and attributions of outcomes (i.e. reflection phases) were observed very seldom (Sobocinski et al., 2017). In a very similar setting, Järvelä et al. (2016) also found a low frequency of occurrence for reflection phases when teacher education students worked on mathematics problems assigned by the instructor or collaboratively constructed a mathematics didactic plan. Furthermore, also using a comparable setting, Malmberg et al. (2017) showed that the frequency and total duration in single learning session was highest for co- and lowest for self-regulated task understanding, goal setting and planning processes. Mean duration was highest for task execution, followed by socially shared processes related to achieving task understanding, setting goals and planning and lowest for self-regulated processes of strategy use, monitoring and evaluation. Furthermore, the authors could show sequential associations between various types and processes of regulated learning and task execution. For example, socially shared monitoring, evaluating and strategy use processes were often followed by task execution activities, which in turn were often followed by co-regulated processes of monitoring, evaluating and strategy use. In line with the latter finding, Schoor and Bannert (2012), who used process mining methods to re-analyze data from a study in which students had to create a handout on the significance test in pairs communicating via a course management system, identified as one common pattern a cycle of working on the task and monitoring of progress. Activities related to goal setting, planning and evaluating work were relatively seldomly observed. Thus, overall, the reviewed studies relatively unanimously show that (a phase of) reflection or evaluation activities occurs seldom when students work in groups of two or more on a mathematics task, or at least, is difficult to observe. Furthermore, the importance of a performance phase, respectively (socially shared) activities of monitoring, strategy use and task completion and their connectedness, seems also relatively well documented. Concerning the planning phase, and activities of analyzing the task, setting goals and planning, results are less consistent.

Furthermore, the reviewed studies generally confirmed the notion that self-regulated learning is not static but underlies changes. An increasing occurrence of the performance phase, respectively the use of learning strategies, over time was found not only for student groups working collaboratively on a mathematics didactic plan in multiple sessions over several weeks (Järvelä et al., 2016) but also for instructor-student dyads discussing a students' task (i.e. a learning portfolio in a course on research methodology and data analysis) at the beginning and end of an academic year (Hadwin et al., 2005). Yet, for the phase of forethought respectively activities of goal setting and planning, based on the reviewed studies no clear developmental trend could be identified. Järvelä et al. (2016) found a decrease in the occurrence of forethought over several weeks when student groups worked on tasks in multiple sessions. Yet, this trend could only partially confirmed by Bellhäuser et al. (2016), who examined the effects of a web-based training of self-regulated learning and learning diaries in a sample of prospective students participating in an online preparatory mathematics course. Of relevance here is that for the control group, which was not subjected to any intervention, a decrease for goal setting but an increase for planning were observed over the four-weeks-course. Similarly, when zooming in on single learning session, Malmberg et al. (2017) identified a significant increase from the starting to the intermediate phase for socially shared processes of achieving task understanding, setting goals and planning. And Hadwin et al. (2005) found no significant changes regarding the occurrence of the phases of goal setting and planning in discussions between instructors and students over the course of the academic year. Results are also ambiguous regading the temporal development of phases or activities of reflection and evaluation, as both increases (Järvelä et al., 2016) and decreases (Bellhäuser et al., 2016) over the course of several weeks have been observed.

With respect to the temporal development of aspects of self-regulated learning, evidence is overall rather ambiguous. For example, in the case of metacognitive aspects, Hadwin et al. (2005) found an increasing occurrence in the student-instructor discussions over the course of an academic year. Yet, Hodges and Kim (2010), who investigated the effect of sending emails designed to support self-regulation strategies to students enrolled in an online mathematics course, could not find significant changes in students' self-reported use of metacognitive self-regulation strategies over a four-months-course, neither in the experimental nor in the control group and, as described above, Bellhäuser et al. (2016) found decreases in reflection and goal setting but increases in planning behavior over the course of several weeks. Evidence for motivational aspects in general and self-efficacy in particular is even more scattered.

Bellhäuser et al. (2016) found a decrease of the first and an increase of the latter over several weeks. However, other studies could not confirm these changes over the course of an academic year (Hadwin et al., 2005) or several months (Hodges & Kim, 2010). For cognitive, behavioral and affective aspects, evidence was scarce to non-existent. The only results available are those by Hadwin et al. (2005), who found a decrease of discussions focusing on cognitive aspects, but an increase of behavioral aspects.

3.4.2.2. Correlates of self-regulated learning

The reviewed studies explored the relationship of self-regulated learning with various constructs. Yet, as many studies used cross-sectional designs, existing evidence does not allow to draw any strong conclusions regarding the causal direction of the relationships.

The correlate targeted most often was mathematics achievement. Evidence regarding this correlate is best for self-efficacy, for which several studies (Cho & Heron, 2015; Hodges & Kim, 2010) found a significant positive association of the respective subscale of the MSLQ (Pintrich et al., 1991) with mathematics achievement. For example, a cross-sectional study by Cho and Heron (2015) found a significant small positive correlation between students' self-efficacy and their final grades in online remedial mathematics courses. Furthermore, in this study, self-efficacy also emerged as the only significant predictor of grades among various (meta-)cognitive, motivational, and affective aspects of self-regulated learning and was significantly higher among students passing the courses compared to those failing them. Furthermore, Zimmerman et al. (2011) who implemented an intervention aimed at supporting students' self-reflective skills in developmental and introductory college level mathematics courses also found significant positive correlations between students' self-efficacy and their test performance during the semester as well as their exam performance at the end of the semester, which were medium to large depending on the sample and the performance measure.

For test anxiety as assessed with the MSLQ (Pintrich et al., 1991), Cho and Heron (2015) found a significant, small negative correlation with mathematics grades and significant differences between students passing or failing mathematics courses in favor of the former. Yet, in another cross-sectional study by Loong (2012), anxiety as assessed with the Learning and Study Strategies Inventory (LASSI) (Weinstein, 1988) did not significantly predict grades of students enrolled in mathematics courses preparing them for their university studies in Malaysia, and neither did the general motivation scale. In line with the latter finding, Schoor and Bannert (2012) could not find significant differences regarding the frequency of occurrence of motivation regulation activities during the construction of a handout on a statistical topic between student dyads with high- or low-quality handouts.

Similarly, results were not completely unequivocal concerning the positive association of time (and study environment) management and mathematics achievement. Bol et al. (2016) found a positive, medium effect of a web-based training focussing on metacognitive aspects of self-regulated learning and time management on students' exam scores in developmental mathematics courses. Furthermore, significantly more students receiving the training completed the courses (i.e. the final exam) compared to students in the control group. Yet, it needs to be noted that previous achievement was not controlled for. Furthermore, Husman and Hilpert (2007) report a significant, small positive correlation between students' scores on the items of the MSLQ (Pintrich et al., 1991) related to time management at mid-semester and their end-of-semester performance in a web-based basic algebra course. However, in the study by Loong (2012), the time management subscale of the LASSI (Weinstein, 1988) did not significantly predict students' mathematics grades.

For cognitive aspects of self-regulated learning, empirical evidence was too small, scattered and inconclusive to allow statements concerning their relationship with achievement. For metacognitive aspects of self-regulated learning instead, an abundance of results was found. The majority of them point to a positive relationship with mathematics achievement. Most notably, experimental studies found positive, small to medium effects of self-regulated learning related trainings with a strong metacognitive focus on mathematics achievement. Zimmerman et al. (2011) report that, compared to control classes taught traditionally, students in classes receiving a training of their self-reflective skills showed better performance on most mathematics tests during the semester as well as on the final exam, with effect sizes ranging from small to medium depending on the sample and performance measure. Furthermore, the intervention classes also had significantly higher pass rates. In addition, among students receiving the training, those making more frequent use of the self-reflection tool implemented as part of the intervention showed significantly better test and exam performance, again, with small to medium effect sizes. Further support (although with a quasi-experimental repeated measures design) for the effects of this intervention is provided by Hudesman et al. (2014) who found that both mean grades and pass rates of developmental mathematics courses at community colleges improved significantly after its implementation. And, as noted above, Bol et al. (2016) also report a positive medium effect on achievement for their web-based training of metacognitive aspects of self-regulated learning and time management.

Non-experimental cross-sectional studies provide further support for a positive association (Loong, 2012; Muis, 2008; Villavicencio & Bernardo, 2016). For example, a significant small positive correlation between the metacognitive self-regulation subscale of the MSLQ (Pintrich et al., 1991) and mathematics course grades was reported by Villavicencio and Bernardo (2016) for engineering students enrolled in trigonometry courses. And in a study by Muis (2008), students with different epistemic belief profiles (i.e. beliefs about the derivation and justification of knowledge) not only differed significantly concerning their self-reported and actual use of metacognitive self-regulation strategies, but also concerning their mathematics problem-solving performance (which the author attributed to their metacognitive strategy use). It needs to be noted though, that there are also experimental (Hodges & Kim, 2010) and non-experimental studies (Cho & Heron, 2015; Schoor & Bannert, 2012) which could not confirm a significant relationship between metacognitive aspects of self-regulated learning, respectively social metacognitive regulatory activities and mathematics achievement. To complicate the picture even more, a cross-sectional study by Villavicencio and Bernardo (2013) suggests a potential moderator effect. In a sample of first-year students enrolled in trigonometry courses, metacognitive self-regulation as assessed with the MSLQ (Pintrich et al., 1991) was positively related with grades for students reporting high levels of enjoyment and pride. In contrast, for students reporting low levels, self-regulation was not related to grades in the case of pride and even negatively in the case of enjoyment.

Beyond achievement, based on the reviewed studies, it seems appropriate to propose that self-regulated learning (respectively specific constructs subsumed under this umbrella term) is positively associated with several motivational and affective variables. For example, Husman and Hilpert (2007) found significant positive, small correlations between students' endogenous perceptions of instrumentality assessed at the beginning and end of a semester and their mid-semester scores on the time management-related items of the MSLQ (Pintrich et al., 1991). Furthermore, using a repeated measures experimental design, Acee and Weinstein (2010) found a positive effect of an intervention supposed to enhance the perceived value of learning statistics through persuasive messages and use of value-reappraisal strategies on the endogenous instrumentality of learning statistics reported by students, which was large immediately after the intervention and still medium in size two weeks later.

For self-efficacy, correlations with (other) constructs of self-regulated learning found in the reviewed studies were significant, positive and small (Husman & Hilpert, 2007) to large (Villavicencio & Bernardo, 2016) in size. In addition, Bellhäuser et al. (2016) found positive effects of their web-based training of self-regulated learning on self-efficacy among participants of an online preparatory mathematics course. And in a cross-sectional, mixed methods study by Cifarelli et al. (2010), different strategies for solving mathematics problems could be identified among students from a college algebra course depending on their mathematics and self-efficacy beliefs. Most students who strongly favored the belief that mathematics is based on the use of memorized procedures imitated existing solution strategies when solving mathematics problems. In contrast, students with a less strong favor for this belief systematically tried different strategies and monitored and evaluated the respective results. Also, students with higher self-efficacy concerning mathematics tended to show higher persistence when facing difficulties and higher complexity of problem-solving strategies. However, none of the observed differences was tested for significance.

Beyond this, two studies found significant positive, large correlations between metacognitive self-regulation as assessed with the MSLQ (Pintrich et al., 1991) and enjoyment and pride related to mathematics courses (Villavicencio & Bernardo, 2013, 2016). In addition, Villavicencio and Bernardo (2016) showed that enjoyment and pride were significant and positive predictors of metacognitive self-regulation beyond anxiety.

With respect to demographic characteristics, based on the reviewed studies, it can tentatively be assumed that students' nationality or ethnicity is related to self-regulated learning. Strongest evidence is provided by an experimental independent measures study by Shi et al. (2013). In a collaborative statistics learning situation, the ratio of invidually oriented self-regulated learning (i.e. being concerned with individual goals and relying on oneself) to socially oriented self-regulated learning (i.e. being concerned with group performance and the benefits for and opinions and needs of the partner and sharing understanding and interest) was significantly higher for pairs consisting of two Canadian students or one Canadian and one Chinese student compared to pairs consisting of two Chinese students. For the mixed pairs, an additional analysis showed that within the pairs, the Canadian students had a significantly higher ratio of invidually to socially oriented self-regulated learning compared to the Chinese students. Furthermore, Loong (2012) showed that different subscales of the LASSI (Weinstein, 1988) emerged as significant predictors of mathematics achievement for international and domestic students in Malaysia and Fong et al. (2015) found that self-efficacy for self-regulated learning significantly predicted achievement only for Hispanic and European American but not African American students enrolled in developmental mathematics courses at community colleges. Both cross-sectional studies also found mean level differences concerning self-regulated learning between the different groups. With respect to gender however, based on the reviewed studies, there is no reason to assume that an association with self-regulated learning exists, at least not for metacognitive aspects (Villavicencio & Bernardo, 2016; Winne & Muis, 2011).

Two of the reviewed studies examined the domain-specificity of self-regulated learning. Using a within-subjects experimental design, Winne and Muis (2011) compared the calibration (i.e. the alignment of subjective perceptions with objective states) of undergraduate and graduate student volunteers regarding their general, word and mathematics knowledge. Relative to the other two domains of knowledge, calibration was significantly worse for mathematics, although in absolute terms, calibration was high for all three knowledge domains. Partial support for domain-specificity was also provided by Rotgans and Schmidt (2009). The authors testet the domain-specificity of the MSLQ (Pintrich et al., 1991) in a sample of participants of a general first-year curriculum in Singapore by having them answer a general version of the questionnaire at the beginning and versions specific to their English, science, and mathematics courses at the end of the first semester. Results showed significant differences for the latent means of several subscales between the different course-specific versions as well as a higher predictive validity for achievement for several subscales of the course-specific versions compared to the general version. Specifically, for task-value, time and study management, metacognitive self-regulation and elaboration, the authors found significantly higher latent means on the MSLQ (Pintrich et al., 1991) for mathematics and science compared to English, and the reverse pattern for self-efficacy. Correlations with course grades were significantly higher for the course-specific subscales compared to the general subscales for intrinsic and extrinsic goal orientation in science, self-efficacy in science and English as well as effort regulation in mathematics and science. In addition, when comparing the correlations between course-specific subscales and grades to that of general subscales and the average of the three course grades, correlations were significantly higher for course-specific grades and self-efficacy in mathematics and science as well as effort regulation in mathematics. Yet, no significant significant differences were found in the factor structures underlying the learning strategies and motivational subscales between the different domains.

Lastly, there is initial evidence that the type and challenge level of tasks as well as different interactions in a group might be associated with patterns and processes of self-regulated learning. Both Järvelä et al. (2016) and Sobocinski et al. (2017) identified frequent co-occurrences of specific interaction types and phases of self-regulated learning when student groups worked on tasks. In addition, using an experimental repeated measures design, Järvelä et al. (2016) found differences concerning these associations as well as differences concerning the frequency of their occurence over time between situations in which groups worked on problems assigned by the teacher and situations, in which they worked on a didactic concept on their own. And in the longitudinal study by Sobocinski et al. (2017), different process models emerged for learning episodes rated by groups as high or low in challenges concerning cognition, motivation and emotion. Yet, no significant differences between low- and high challenging situations were found concerning the frequency of self-regulated learning phases and associated interactions.

3.4.3. **Possibilities to support self-regulated learning**

Overall, the review yielded enough evidence for positive effects of trainings and educational interventions on self-regulated learning to assume that such endeavours are worthwile. For example, Bellhäuser et al. (2016) implemented a web-based training of self-regulated learning and learning diaries in an online preparatory mathematics course. The training, which was conducted in three sessions over four weeks, introduced participants to relevant concepts and animated them to apply them in various activities. In the diaries, participants answered questions related to self-regulated learning and self-efficacy both before and after learning on a particular day. Pre-post-tests showed positive training effects but no additional effects for the diaries on self-regulated learning knowledge and self-reported behavior.

In particular for metacognitive aspects as well as for time and study environment management, evidence for positive effects of trainings and interventions clearly outweigh evidence for non-significant or negative effects. For instance, Bol et al. (2016) implemented a three-week-long web-based training of self-regulated learning in developmental mathematics courses. The training consisted of four activities focussed on managing study time, setting goals and planning, monitoring and reflecting study activities, which students completed weekly. A post-intervention evaluation showed significant differences in favor of the students receiving the training compared to the control group regarding metacognitive self-regulation and management of time and study environment. Positive effects for metacognitive aspects, in particular students' calibration (i.e. the match between their self-efficacy for solving mathematics problems or their confidence about the correctness of their solutions and their actual performance on these problems) were also found for the training described by Zimmerman et al. (2011). The training was conducted in mathematics courses taught face-to-face and included activities by instructors (i.e. modelling how to correct errors and change problem solving strategies, emphasizing the importance of these activities and frequently administering and feedbacking quizzes) as well as activities by the students (i.e. judging their self-efficacy before and their confidence about the correctness of the solution after solving mathematics problems, reflecting on these judgements and their problem-solving strategies and adapting them). Students receiving the training showed better calibration concerning their self-efficacy and self-evaluation judgements compared to the control groups. Effects were small in introductory college level classes and medium in developmental classes. In addition, Davaanyam and Tserendorj (2015) identified significant differences in favor of a web-based compared to a face-to-face version of a compulsory mathematics course regarding self-reported metacognitive learning strategies and time and study environment management of first-year students in Mongolia.

However, a non-experimental study by Talbert (2015) found only tentative evidence for changes in students' self-regulated learning due to using an inverted-classroom design in a mathematics course. Students' scores on the MSLQ (Pintrich et al., 1991) did not change significantly over the course of the semester. Unfortunately, no respective data from classes taught traditionally was available to compare the results with. Students' answers to open questions suggested that they benefitted from the course in terms of attitude towards and learning strategies for mathematics as well as, although to a lesser extent, regarding general learning strategies such as time management. Moreover, using a repeated measures design, Hodges and Kim (2010) could not find significant effects for email messages supposed to trigger the use of self-regulation strategies, which they sent to students in an online mathematics course for eleven weeks, on self-reported use of metacognitive self-regulation strategies. And Bellhäuser et al. (2016) found a higher decrease in self-reported self-reflection among students who had received the web-based training compared to the control groups, whereas positive training effects were found for planning and goal setting.

Evidence was too small and ambiguous to draw any conclusions about the malleability of cognitive aspects. For motivational aspects, and in particular for self-efficacy, the majority of reviewed studies could not confirm significant effects of self-regulated learning related trainings or interventions (Hodges & Kim, 2010; Zimmerman et al., 2011). For example, the value-reappraisal intervention implemented in the study by Acee and Weinstein (2010) was successful in enhancing students' task value and endogenous instrumentality but did not have significant effects on students' self-efficacy. Only Bellhäuser et al. (2016) found positive effects of their training on students' self-reported self-efficacy. Lastly, some hints about opportunities to improve self-regulated learning through instruction can also be retrieved from the study by Hoops et al. (2016). The authors developed an instrument to record instructional practices, which could support students' self-regulated learning strategies and used it in undergraduate precalculus courses. Results included an in-depth description of the practices identified. For example, remarks regarding students' metacognition, for example encouraging students to reflect on problem solving strategies, were observed relatively often. However, the study did not test whether the strategies identified actually did support students' self-regulated learning.

3.5. Discussion

In this review, research on self-regulated learning relevant to mathematics tertiary education was systematically searched for in various databases and through other ways, filtered according to predefined selection criteria in a two-tiered process and synthesized in a structured format guided by predefined research questions. Guided by those research questions, the results of the review will be discussed in the following. Afterwards, implications for research and practice will be described and limitations of the study will be pointed out.

3.5.1. Current state of research

Research question 1a referred to the topics, which had been addressed in research on self-regulated learning in mathematics tertiary education. According to an analysis of the research questions and hypotheses of the reviewed studies, commonly addressed topics in the last 19 years were the associations of self-regulated learning or socially shared regulated learning with mathematics achievement and other variables, effects of self-regulated learning related trainings and interventions and phases or temporal sequences of self-regulated learning, co-regulated learning or socially shared regulation of learning. Furthermore, when dividing the time frame examined in the current study into periods of (approximately) 5 years, some trends became obvious, especially a recent increased interest in phases and temporal sequences of self-regulated learning, co-regulated learning or socially shared regulation of learning. To the author's knowledge, to date, no similar analysis has been conducted in the field of self-regulated learning research. Thus, the results cannot be related to previous research, but instead can serve as an inspiration and potential benchmark for future studies (see section 3.5.4).

In order to answer research question 1b, it was analyzed, which theories had framed research. The results showed a clear theoretical dominance of the research groups around Zimmerman (Zimmerman, 1989, 2000; Zimmerman & Martinez Pons, 1986), Pintrich (Pintrich, 2000b; Pintrich et al., 1991) and Winne (Winne & Hadwin, 1998) for the whole timespan covered by the review. In the case of Zimmerman, especially the Cyclical Phases of Self-Regulated Learning model (Zimmerman, 2000) had a strong impact on the work of other researchers. The next most important researcher based on the number of overall references to his work was Pintrich. More often than the framework (Pintrich, 2000b) however was it the MSLQ (Pintrich et al., 1991) which was either cited or simply used as a measurement instrument, the latter being the more typical event. It needs to be noted that the MSLQ (Pintrich et al., 1991) was constructed before Pintrich finalized his framework (2000b) and thus does not completely represent it (Pintrich, 2004). Nonetheless, Pintrich himself described how the MSLQ (Pintrich et al., 1991) relates to his framework (2000b) and thus, clearly connected these two (Pintrich, 2004). Furthermore, also the model by Winne and colleagues (Winne & Hadwin, 1998) framed research often, again, most of the times in form of citations.

Overall, the results align well with those of other meta-analyses and reviews of self-regulated learning research. Especially Zimmerman's Cyclical Phases of Self-Regulated Learning model (Zimmerman, 2000) has repeatedly been identified as the most frequently used theory in research on self-regulated learning (Adam et al., 2017; Moos & Ringdal, 2012). Best aligned with the current results is a review focusing on self-regulated learning in computer-based learning environments by Winters et al. (2008), which also identified Zimmerman's Cyclical Phases of Self-Regulated Learning model (Zimmerman, 2000), Winne and Hadwins' (1998) model and Pintrichs framework (2000b) as the most commonly used theories. Furthermore, the results also align in part with the review by Panadero (2017), which showed that, compared to other common theories, Zimmerman's Cyclical Phases of Self-Regulated Learning model (Zimmerman, 2000) and Pintrich's framework (2000b) had by far the highest number of citations per year. However, according to the latter analysis, Boekaerts Dual-Processing Self-Regulation model (Boekaerts & Corno, 2005) and Winne and Hadwins' (1998) model had a similar number of citations per year. In contrast to this, in the current review, Winne and Hadwins' model (1998) was found to frame research almost six times as often as the Dual-Processing Self-Regulation model (Boekaerts & Corno, 2005). Also, whereas Panadero (2017) found a higher number of citations for the model by Efklides (2011) compared to the model by Hadwin et al. (2018), the former model was not referred to at all by the studies included in the current review. For the model by Hadwin et al. (2018) however, a late but strong start was detected. This aligns well with the observation by Hadwin et al. (2018) that research on social forms of regulation of learning strongly increased since 2011. Furthermore, it is also plausible when considering that this model was developed later than the other models examined, as the first systematic description was published in 2011 (Hadwin et al., 2018; Hadwin et al., 2011; Panadero, 2017).

Another finding to be examined critically is that the majority of articles used more than one theory as the basis for argumentation and/or research. Based on this result alone, it cannot be decided whether this indicates a trend towards an enriching synthesis of several theoretical models or theoretical confusion. To further explore this question, studies using just one theory were compared to those using more than one theory regarding several other characteristics (see appendix 7.3 for the respective tables). Results showed that the percentage of studies using explicit definitions was clearly higher among studies using more than one compared to those using just one theory as the basis for research and/or argumentation (see Table 19). The same pattern was found for the percentage of studies explicitly stating to build on at least one theory (see Table 20), whereas the reverse pattern emerged for the percentage of studies, which were rated as having ill or partial alignment between theory and measurements (see

Table 21). In sum, the author of this dissertation believes that the multiplicity of theories used as a basis of research and/or argumentation is not necessarily an indicator of theoretical confusion and consequentially low quality but rather of a well-thought, valuable, synthesis.

Guided by research question 1c, the current review explored how self-regulated learning had been defined in the reviewed studies. Results showed that explicit and implicit definitions had been used equally often. If authors did not give an explicit definition of self-regulated learning, in most cases they at least elaborated on the concept, sometimes with a special focus on the work of specific researchers (i.e. they used conceptual or conceptual and referential definitions). Very few studies only referred to work of others and in no study did the measurement instrument provide the only information about the definition of self-regulated learning. These results stand in contrast to those of Dinsmore et al. (2008), who, based on a similar analysis, reported that the great majority of studies in the field of self-regulated learning used explicit definitions. A possible reason for the differing results is that the definition of explicit definitions was handled more strictly in the current review. Furthermore, it needs to be noted that when focusing only on the last four years of research also in the current review did explicit definitions clearly outweigh implicit ones. This suggests a potential positive development, especially in light of the broad variety of theoretical models and definitions which exist for self-regulated learning (Dignath & Büttner, 2008).

Furthermore, with respect to research question 1c, it was also examined on which aspects of self-regulated learning the studies focussed. The results showed a strong interest in metacognitive aspects, especially during the last nine years. Several reasons might have caused this interest. On the one hand, metacognition has been identified as playing an important role in mathematics (Carr & Biddlecomb, 1998; Pape & Smith, 2002) and the studies might reflect this. On the other hand, a lacking consistency in defining metacognition, respectively metacognitive learning strategies and in differentiating it from self-regulated learning has been detected by other researchers (Dignath et al., 2008; Sitzmann & Ely, 2011; Winters et al., 2008). In line with this, when examining the specific metacognitive aspects targeted, it became obvious that many of the studies focussed on the triad of planning, monitoring and regulating. Especially for monitoring and regulating, a conceptual overlap between metacognition, self-regulation and self-regulated learning has been identified (Dinsmore et al., 2008). Moreover, in the MSLQ, which was the most frequently used instrument in the studies reviewed, one specific subscale is called metacognitive self-regulation and assesses exactly these three aspects (Pintrich et al., 1991). Thus, it might be hypothesized that some researchers adopted a narrow definition of self-regulated learning, equating it with metacognitive monitoring and control of cognition. In support of the latter interpretation, in six of the nine studies investigating only one aspect of self-regulated learning, this aspect was metacognitive in nature and in four of them (Bol et al., 2016; Muis, 2008; Villavicencio & Bernardo, 2013, 2016), the metacognitive self-regulation subscale of the MSLQ (Pintrich et al., 1991) was used. An additional observation deserving attention was the multiplicity of aspects addressed by the majority of studies. This result stands in contrast to the finding by Winters et al. (2008) that among studies examining self-regulated learning in computer based learning environments, many focused on a singular aspect. However, it is in line with the characterization of self-regulated learning as an umbrella term for a broad variety of constructs (Panadero, 2017; Roth et al., 2016).

Research question 1d focused on the research design of the reviewed studies. Overall, most studies were conducted in a field setting and were based on primary data analyses. The most common experimental designs were non-experimental studies, the majority of them cross-sectional ones. The latter results stand in contrast to those of a recent meta-analysis examining the association of self-regulated learning strategies and academic achievement in online learning contexts by Broadbent and Poon (2015). In that study, the most common designs by far were longitudinal non-experimental studies, whereas experimental and cross-sectional studies were found relatively seldom. However, it is not clear how exactly the authors defined the categories, which might be one explanation for the differing results. Although cross-sectional field studies were most common in the current review, several other study designs were observed as well. For example, laboratory studies as well as (quasi-)experimental studies first emerged in the period between 2010 and 2014 but have been well-represented since. Especially positive is the finding that almost one quarter of the reviewed studies used experimental designs with multiple measurement points and the majority of them were field studies. This study design has several strengths, for example with respect to internal and external validity (Döring & Bortz, 2016). Worst-represented were laboratory experimental studies using an independent measures design (only one study was classified accordingly), and not represented were cross-sectional studies conducted in a laboratory. Both designs have major weaknesses (Döring & Bortz, 2016), for example with respect to internal and external validity, and thus, this gap in the literature is not considered critical.

In order to answer research question 1e, it was examined which instruments had been used in the reviewed studies to measure self-regulated learning. In line with the findings of other reviews of self-regulated learning research (Dinsmore et al., 2008; Moos & Ringdal, 2012; Winters et al., 2008), most instruments used could be classified as self-reports. Among these, questionnaires were by far the most commonly used type, followed by think-alouds, diaries and interviews. These results confirm those of a review of self-regulated learning research by Dinsmore et al. (2008) and a review of measurement instruments of self-regulated learning by Roth et al. (2016). Furthermore, in line with the results of the latter review, about two thirds of the self-reports used were (adapted) established instruments. However, Roth et al. (2016) did not differentiate between different types of self-reports, which limits the comparability of the results. For example, they report that about one quarter of the studies used self-constructed measures. Yet, in the current review, the percentage of self-constructed instruments varied greatly between different types of self-reports: All think-alouds, diaries and interviews, but only 12% of the questionnaires used were self-constructed. Other types of measures used in the reviewed studies included observations, traces and tests. Compared to the results reported by Dinsmore et al. (2008) think-alouds and interviews were represented worse and observations better. Furthermore, for observations, an upward trend over time could be observed, which might indicate that researchers acknowledged the theoretical trend to describe self-regulated learning as a process (e.g. Boekaerts & Corno, 2005) as well as the widespread critique of self-reports (e.g. Boekaerts & Corno, 2005; Spörer & Brunstein, 2006; Winne, 2010). However, this trend did not hold for other methods of assessment such as traces, which have also been suggested to be an alternative to self-reports (e.g. Azevedo & Witherspoon, 2009; Winne, 2010).

A further distinction to be discussed is that between classical questionnaires and ratings of self-efficacy or correctness of answers shortly before or after answering a specific task. In the current review, both types of questions were subsumed under the category of questionnaires, however, other researchers have suggested that there exist differences between these types of measures (Dinsmore et al., 2008). Two of the reviewed studies (Muis, 2008; Zimmerman et al., 2011) used such measures, i.e. 7% of all reviewed studies. This percentage is slightly higher than that reported by Dinsmore et al. (2008) in a review of self-regulated learning research, however, their definition of the measures might not have been exactly the same. The single most often used instrument to assess self-regulated learning was the MSLQ (Pintrich et al., 1991), in adapted form. In this respect, the current review thus corroborates findings of several other meta-analyses and reviews (Broadbent & Poon, 2015; Moos & Ringdal, 2012; Roth et al., 2016). A minor point to be noted in this respect is that even though the MSLQ (Pintrich et al., 1991) was originally designed as a 7-point-Likert scale (Duncan & McKeachie, 2005; Pintrich et al., 1993), several studies used a 5-point scale, without explaining this (Husman & Hilpert, 2007; Rotgans & Schmidt, 2009; Villavicencio & Bernardo, 2013, 2016). Most studies used only subscales of the MSLQ (Pintrich et al., 1991), this is in line with the intentions of the creators (Duncan & McKeachie, 2005; Pintrich et al., 1993).

Research question 1f referred to the target groups, which had been studied. Several findings emerged which can be compared to results of other reviews in the field of self-regulated learning research. For example, in the current review, small samples ($N < 100$) as well as medium-sized (i.e. $100 \geq N \leq 400$) samples each were used by almost half of the reviewed studies, whereas only less than one quarter of the studies used at least one large sample ($N > 400$). Thus, small samples were overrepresented compared to the results reported by Roth et al. (2016), who, based on the same criteria, found that only about one quarter of the reviewed studies used small samples. A potential explanation for this difference is that Roth et al. (2016)'s review focussed only on self-report instruments, whereas in the current review, studies using other methods such as observations and traces, which are typically associated with smaller samples, were included as well. Although nearly half of the reviewed studies had been conducted in the U.S., research had also been conducted in other areas of the world, including Europe and (South) East Asia. Compared to the samples identified in a recent meta-analysis concerning the relationship between personal epistemology and self-regulated learning strategies (Alpaslan et al., 2017), North American samples were represented better and Asian sample represented worse. However, compared to a meta-analysis concerning the relationship of MSLQ (Pintrich et al., 1991) subscales and academic achievement in college, in which nearly 90% of studies were conducted in North America (Credé & Phillips, 2011), the dominance of North American samples was far less pronounced in the current study. Furthermore, since it was not deemed appropriate to conduct a meta-analysis (see section 3.5.6), how the country where research was conducted might have impacted the results remains to be determined. The results of the meta-analysis by Alpaslan et al. (2017) as well as those of meta-analyses for specific self-regulated learning related constructs such as achievement goals (e.g. Huang, 2012; Hulleman et al., 2010) or attributions (Mezulis et al., 2004), suggest that respective effects might exist. In any case, it can be stated based on the results of the current review that self-regulated learning in mathematics tertiary education is a topic of international interest. It needs to be noted though that for many studies, information about the country in which research was conducted was not provided explicitly, but rather was inferred from the author's affiliations. Similarly, due to lacking consistent information, no statements can be made regarding potential effects of gender, age, degree of study, level of education or other characteristics of participants or institutions based on the current review. It can only be observed that existing research on self-regulated learning in mathematics tertiary education was relatively well-balanced concerning participants' age and year in college, but that samples from public universities, and with a female, or Caucasian (white, European American, Caucasian or Caucasian American) majority were somewhat overrepresented.

3.5.2. Nature and correlates of self-regulated learning

In order to answer research question 2, tentative conclusions about the nature and correlates of self-regulated learning in mathematics tertiary education were drawn based on the findings of the reviewed studies. A detailed elaboration of these conclusions as well as the findings and characteristics of specific studies was already provided in the respective result sections (see sections 3.4.2.1 and 3.4.2.2). At this point, only the major conclusions will be presented again and discussed in light of previous research and theoretical considerations.

Two major conclusions regarding the nature of self-regulated learning in mathematics tertiary education could be drawn. First, self-regulated learning in mathematics tertiary education is best described as a process consisting of different phases and activities occurring with variable frequency and potentially also in recursive loops instead of a simple linear sequence. Especially the performance phase, and the (socially shared) activities of monitoring, strategy use and task completion it includes, seems to occur frequently, whereas reflective and evaluative activities are rarely observed. Concerning the frequency of occurrence of the planning phase, respectively activities of analyzing the task, setting goals and planning, the reviewed studies yielded ambiguous findings. Second, self-regulated learning in mathematics tertiary education is amenable to change over time. Yet, only for the performance phase and the use of learning strategies in particular, results relatively consistently pointed to an increasing occurence over time spent working on a task, whereas results did not allow any conclusions about the direction of change for the phases of forethought (i.e. goal setting and planning activities) and reflection or evaluation. Similarly, for aspects of self-regulated learning, existing evidence was rather ambiguous and scattered. However, also among studies taking this line of sight, some did identify significant changes over time.

Overall, the conclusions emerging based on the reviewed studies align well with general theoretical discussions and positions in the field of self-regulated learning research. For example, whereas early research commonly conceptualized self-regulated learning as stable, more recent approaches suggest that self-regulated learning is best viewed as a process, which consists of numerous activities or phases and recursive loops and is dynamic and susceptible for the situation in which it occurs (Boekaerts & Corno, 2005; Cascallar, Boekaerts, & Costigan, 2006; Dent & Koenka, 2016; Pintrich, 2000b; Winters et al., 2008). For example, Pintrich (2000b, 2004) stressed that the phases he proposed in his framework did not imply a linear sequence but instead, that especially the phases of monitoring and control were closely linked. Similarly, according to the model of Winne and colleagues (Winne & Hadwin, 1998), self-regulated learning is a process consisting of different, interrelated phases which do not have to be completed in a strict linear order. Furthermore, the model assigns particular importance to monitoring and control activities which are assumed to influence every phase of the process (Greene & Azevedo, 2007). In addition, the review demonstrates that with respect to mathematics tertiary education, relatively broad evidence is already available for a topic that a previous meta-analysis of self-regulated learning research (Sitzmann & Ely, 2011) identified as central for future research: The temporal development of self-regulated learning and its contextual dependency.

The best-researched correlate of self-regulated learning was mathematics achievement. Based on the results of the reviewed studies, small to medium positive associations with mathematics achievement can be assumed with relative certainty for metacognitive, motivational (i.e. self-efficacy) and behavioral (i.e. time management) aspects of self-regulated learning. In contrast, no conclusions could be drawn regarding the association of cognitive and affective aspects with mathematics achievement. Moreover, as many of the studies used cross-sectional designs, causal inferences as well as conclusions regarding the direction of these associations are generally deemed inappropriate. At most, based on the improvement of mathematics performance found after the implementation of a training of self-reflective skills in a well-designed experimental repeated measures field study (Zimmerman et al., 2011), one could formulate the tentative hypothesis that metacognitive self-regulation has a positive effect on mathematics achievement. Nonetheless, these conclusions align well with the theoretical assumption of most major self-regulated learning models that self-regulated learning is related to achievement (e.g. Pintrich, 2000b). Even more importantly, they are in line with the results of other reviews and meta-analyses of self-regulated learning research, which also found positive associations with achievement for self-efficacy (Richardson et al., 2012; Robbins et al., 2004), metacognitive strategies (Broadbent & Poon, 2015; Dent & Koenka, 2016; Richardson et al., 2012), and time and study environment management (Broadbent & Poon, 2015; Richardson et al., 2012). A comparison with previous meta-analyses further highlights gaps in the research on self-regulated learning in mathematics tertiary education. For example, previous meta-analyses (Broadbent & Poon, 2015; Richardson et al., 2012) found a positive relationship between critical thinking and academic achievement, whereas in the current review, the only study which explored it could not confirm a significant relationship (Cho & Heron, 2015). Other constructs for which a positive association with achievement could be expected based on previous meta-analyses (Broadbent & Poon, 2015; Richardson et al., 2012) but for which evidence in the current review was too small to draw any conclusions include task value, mastery or learning goals, effort regulation, help seeking and peer learning. Lastly, a negative association with achievement for test anxiety could be found in some (Richardson et al., 2012), but not all (Fong et al., 2017) previous meta-analyses and ambiguous results with respect to test anxiety were also found in the current review. Beyond this, it should be noted that recent meta-analyses reported that the study design (Richardson et al., 2012) and the measurement instruments (Dent & Koenka, 2016) can moderate the relationship of self-regulated learning with academic achievement. Thus, if future studies used different designs or instruments, they might also come to other conclusions about the relationship of self-regulated learning with academic achievement.

Beyond achievement, based on the reviewed studies, several other correlates of self-regulated learning could also be identified. In particular, positive associations with self-regulated learning were relatively consistently found for endogenous perceptions of instrumentality, self-efficacy, enjoyment and pride. Based on the reported correlations and effect sizes, the relationship can be assumed to be strong in case of enjoyment and pride, whereas for endogenous perceptions of instrumentality and self-efficacy, the strength of the effects found was less consistent. Students' nationality or ethnicity were also repeatedly found to be related to self-regulated learning, whereas associations with gender were not supported by the reviewed studies. Lastly, two of the reviewed studies each provided evidence for a (limited) domain- or task-specificity of self-regulated learning in mathematics tertiary education and an association of self-regulated learning with different types of interaction among students in group work. That self-regulated learning was found to be associated with a broad variety of constructs aligns well with the assumptions of many major models of self-regulated learning. For example, the model by Winne and colleagues (Winne & Hadwin, 1998) assumes that cognitive and task conditions, which comprise many of the variables described above, e.g. a person's motivation or the task characteristics, come into play in every phase of the self-regulated learning process, influencing for example the learning strategies people choose (Greene & Azevedo, 2007). Furthermore, previous reviews have also found evidence for associations of the (perceived) learning environment (Greene & Azevedo, 2007; Winters et al., 2008), and self-efficacy (Greene & Azevedo, 2007) with self-regulated learning. Relevant to discuss in this context is further, that, as attentive readers might have realized, self-efficacy was defined by some of the reviewed studies as a subcomponent of self-regulated learning, whereas others defined it as a (separate) correlate. This demonstrates the complexity and lacking conceptual or definitional clarity that is often observed in the research field (Boekaerts & Corno, 2005; Winters et al., 2008). One explanation for this confusion is that the major theoretical models assign different roles to motivational and affective variables. In the Cyclical Phases of Self-Regulated Learning model by Zimmerman (2000) for example, motivational beliefs (and also specifically self-efficacy) are included in the forethought phase. In contrast, Wolters (2003) explicitly differentiates between self-efficacy per se and the regulation of it, respectively more general the regulation of motivation. Thus, the varying conceptualization of self-efficacy might have been caused by different theoretical foci of the studies or differing interpretations of these models.

3.5.3. Possibilities to support self-regulated learning

Research question 3 focussed on possibilities to support self-regulated learning in mathematics tertiary education. In sum, the reviewed studies provided plenty evidence for the existence of such possibilities. Especially metacognitive aspects and time and study environment management seem to be pliable through trainings or other educational interventions, whether they are conducted web-based (e.g. Bol et al., 2016) or face-to-face (e.g. Zimmerman et al., 2011). This conclusion aligns well with previous reviews and meta-analyses, which generally also found that teaching practices (Greene & Azevedo, 2007; Moos & Ringdal, 2012) as well as trainings (Dignath et al., 2008; Dignath & Büttner, 2008; Winters et al., 2008) could support self-regulated learning of students of different ages. Furthermore, for the primary and secondary school level, previous meta-analyses demonstrated that cognitive and metacognitive strategy use and knowledge as well as motivational outcomes and strategies (Dignath et al., 2008; Dignath & Büttner, 2008) were especially enhanced through trainings of self-regulated learning if these were conducted in contexts of mathematics instruction. Unfortunately, these meta-analyses did not differentiate between cognitive and metacognitive strategy use. Nonetheless, their findings leave room for hope that cognitive aspects can be improved through educational interventions or trainings as well, even though the current review did not identify enough studies exploring such effects in order to draw any respective conclusions. A similar situation exists for the construct of self-efficacy. Based on the reviewed studies (Acee & Weinstein, 2010; Hodges & Kim, 2010; Zimmerman et al., 2011), it seems questionable whether self-regulated learning related trainings or interventions can enhance students' self-efficacy. Yet, in contrast to the metacognitive aspects and time management, none of the studies did specifically aim at supporting self-efficacy. In addition, positive effects were not completely non-existent in the current review (see Bellhäuser et al. (2016)) and beyond the current review, positive effects of self-regulated learning supportive instructional methods on self-efficacy (Butler, 1998, 2002) have been reported as well.

3.5.4. Implications for research

The current study can serve as inspiration for researchers in designing future studies in many respects. Firstly, it identified areas where a relatively rich basis of previous research exists and can be built upon (e.g., effects of self-regulated learning related trainings and interventions) as well as interesting but relatively isolated findings which should be further explored in future research (e.g., ethnic, respectively cultural differences concerning self-regulated learning). This does not only apply to topics, but also to instruments, methods, target groups and many other aspects of research. Interested readers are referred to the respective results and discussion sections for more detailed descriptions of the literature base available and are invited to draw their own conclusions about areas in need for further research beyond those identified and discussed there. Secondly, the review itself could be extended in several ways. This will be discussed in the following subsection in connection with the limitations of the current review. Thirdly, based on the findings of the current review, several suggestions concerning the methodological approach as well as the reporting of results of self-regulated learning research can be made.

Most importantly, the author of this dissertation agrees with other researchers that constructs should be defined explicitly and theories on which studies are based identified clearly and elaborated as necessary (Azevedo, 2009; Dent & Hoyle, 2015; Murphy & Alexander, 2000). In the light of these suggestions, the findings of the current study (although based on a relatively strict criterion) that only half of all reviewed studies used explicit definitions of self-regulated learning, but that the respective number increased over time, should be viewed as a motivation for future research to continue this trend. The same holds true for the theoretical basis of studies, for which strengths of the existing literature base (e.g., syntheses of several theories), but also room for further improvement (e.g., explicitly stating on which theory or theories the study builds) could be detected.

Secondly, in the light of constant critique of self-report measures in general and Likert-scale questionnaires in particular (e.g. Boekaerts & Corno, 2005; Dent & Koenka, 2016; Spörer & Brunstein, 2006; Winne, 2010), the finding that the MSLQ (Pintrich et al., 1991) was the most frequently used instrument to assess self-regulated learning and that questionnaires in general were by far the most common type of instrument used points to another limitation of current research which future research should seek to overcome. Again, the current review did identify some already existing positive trends in this respect, for example, an increasing use of observation methods in recent years.

Thirdly, analyses concerning the target groups focused on in previous research were impeded by the fact that information on students' and study characteristics was often lacking. For example, as mentioned above (see section 3.5.1), the country where research was conducted often had to be inferred based on the authors' affiliations. In other cases, information (e.g. age or ethnicity of participants) was not reported in a consistent format across studies. Other researchers conducting meta-analyses in the field of self-regulated learning have encountered similar difficulties (Fong et al., 2017). This is especially critical as both previous meta-analyses (e.g. Hulleman et al., 2010) as well as some of the reviewed studies (e.g. Shi et al.,

2013) suggest that student characteristics such as nationality or ethnicity might related to (aspects of) self-regulated learning. Thus, future studies should report such information as extensively and detailed as possible in order to allow readers to compare and contrast different studies and other researchers to summarize test effects of such variables using meta-analyses.

Lastly and positively, the current review could only partly confirm a critique concerning self-regulated learning research (Martin & McLellan, 2008) that measurement instruments used would not align well with the theories on which studies based. Only four of the reviewed studies were judged as showing ill alignment between definitions and theories framing research and measurement instruments applied. Of those, one referred to Zimmerman's work (1989) in the theoretical background but used the LASSI (Weinstein, 1988) to assess students' learning strategies (Loong, 2012), two referred to work of the research groups around Winne (Winne & Hadwin, 1998) and Zimmerman (Zimmerman & Martinez Pons, 1986) (Zientek et al., 2013), respectively Pintrich (2000b) and Zimmerman (2000) (Fong et al., 2015) but measured it with a scale assessing self-efficacy for self-regulated learning which was partly based on the MSLQ (Pintrich et al., 1991), and one (Hodges & Kim, 2010) referred to Zimmerman's work (1989) but used the MSLQ (Pintrich et al., 1991) to assess self-regulated learning. The fact that the models of Zimmerman (2000) and Pintrich (2000b) share more similarities than many other common models (Puustinen & Pulkkinen, 2001) might have contributed to the mixing of their models and methods (but does not excuse it). In sum, lacking consistency between definitions/theoretical basis and measurement instruments does not seem to be a grave problem of research in the field. Still, it does need to be noted that for several studies, only partial alignment could be found, for example, because not all aspects that were part of the definition were measured. Thus, researchers should continue to be meticulous in defining the constructs they assess, situate them in previous theoretical work where available, choose the measurement instruments accordingly, and, lastly, reveal the considerations involved in this process. This way, readers can judge better, if these decisions were well-founded or rather seem dubious and interpret the results accordingly.

3.5.5. Implications for practice

Based on the results of the current review, there is every reason to believe that (aspects of) self-regulated learning are positively associated with achievement in mathematics (e.g. Husman & Hilpert, 2007) as well as with other positive outcomes such as course satisfaction (Cho & Heron, 2015) and positive academic emotions (Villavicencio & Bernardo, 2013, 2016) and negatively with negative outcomes such as passive procrastination (Dunn, 2014). These findings should motivate practicioners to reflect on the ways in which their instruction is supportive of self-regulated learning. Hoops et al. (2016) provides an instrument for conducting such a reflection based on observational data.

Furthermore, based on the studies reviewed, it seems appropriate to assume that (aspects of) self-regulated learning can be trained, leading to an increase in self-regulated learning behavior and knowledge (e.g. Bellhäuser et al. (2016)) and, although evidence regarding this aspect is not completely unambiguous, potentially also in mathematics achievement (e.g. Zimmerman et al., 2011). Besides trainings, the current review revealed a variety of interventions with supposedly positive effects on self-regulated learning. However, they were very different from each other, ranging from emails (e.g. Hodges and Kim (2010) to complete reorganizations of instruction, (e.g. Talbert, 2015) and not always successful. Still, practicioners are encouraged to test effects of instructional methods on self-regulated learning, especially if implementing a training is considered inappropriate or impossible.

The findings of the current review should also have made practicioners aware of the fact that students' self-regulated learning is related to various individual characteristics such as motivation (Husman & Hilpert, 2007) or ethnicity (Fong et al., 2015; Loong, 2012; Shi et al., 2013). Furthermore, although evidence concerning the domain- and situation-specificity of self-regulated learning was ambiguous, practicioners are still encouraged to reflect on special characteristics of the learning environment in which they teach. Regarding all the relationships stated above, it needs to be cautioned though that no causal relations can be assumed based on the results of the current review.

3.5.6. **Limitations**

Several limitations of the current review need to be noted. Although selecting studies based on pre-defined inclusion and exclusion criteria is necessary for ensuring a systematic approach to searching literature and a criterion for good reviews (e.g. Liberati et al., 2009), these criteria also define the limits of the current review. Most notably, only peer-reviewed journal articles were included in the review. This might have influenced the findings since peer-review has been criticized as being prone to publication bias, i.e. the overrepresentation of significant results (Wolf, Schroeders, & Kriegbaum, 2016). Nonetheless, it was decided to exclude grey literature because the current review was not intended to become a meta-analysis and thus, potential publication bias concerning effect sizes was not considered a major problem. Instead, the aim of the current review was to provide an overview on self-regulated learning research in mathematics tertiary education and to outline major conclusions that could be drawn based on existing research. The review is supposed to serve as an introduction to the field for practicioners and as an inspiration for future studies for researchers. In both cases, the author of this dissertation believes that it is important to be introduced to high quality research. In peer-reviewed journals, the quality of research is ensured by the peer-review, whereas for grey literature, no such quality check exists. For these reasons, the latter were excluded from the current review (see Schneider and Preckel (2017) for a similar argumentation).

Similary, the restriction of including only articles in the review, which mentioned pre-defined search terms in the title or abstract, might seem strict. However, as explained in the methods section (see section 3.3.1), it was deemed necessary due to the broad array of constructs which one might possibly subsume under the umbrella term of self-regulated learning (Panadero, 2017). Without a strict criterion, deciding about the inclusion or exclusion of articles would have become very difficult (e.g. should studies focusing exclusively on self-efficacy be included?) and probably less transparent, as defining inclusion criteria for every specific situation would have been impossible. Including all these studies in one review however would not only be a daunting task, it would also lead to a very complex study and expansive results, difficult to analyze for the author and difficult to understand for the readers. Moreover, other researchers have already provided excellent and recent reviews for many of the self-regulated learning-related constructs (see for example Hulleman et al. (2010) for a meta-analysis on achievement goals).

Further exclusion criteria applied in the current study concerned the context of the studies. In line with the focus of the current review, only studies conducted in the context of mathematics tertiary education were included in the final sample. Thus, in the author's opinion the logical next step would be to extend the review to secondary and primary education as well as to other academic domains. In addition, especially with respect to the mathematics education criterion, it needs to be noted that the implementation of this criterion was not without challenges. The author decided to include not only studies conducted in mathematics courses, but also studies assessing mathematical knowledge or performance, i.e. which were deemed as being directly relevant to mathematics tertiary education. This concerned three studies included in the final sample: Schoor and Bannert (2012) assessed patterns of social regulatory processes while students created a handout on the significance test, Shi et al. (2013) examined the relation of individually to socially oriented self-regulated learning actions of student pairs learning Analysis of Variance and Winne and Muis (2011) analyzed students' calibration concerning their mathematics knowledge. Since it was made transparent, which study contributed in what way to which analysis and which results, readers interested only in studies conducted in mathematics courses can neglect these three studies. Nonetheless, implementing an even broader (or stricter) criterion in future reviews and comparing the results to those of the current review could provide important clues about the relevance of the context or situation for self-regulated learning and thus, enrich research in this field. Lastly, reviews including research published in other languages and before the year 2000 might provide valuable results as well – although in the current review, all articles included in the final review were published in English and not before the year 2005.

Beyond the filtering process, the current study was also limited to some extent concerning the search process as well as the analyses conducted. An effort was made to include databases covering research from different domains and origins. A German database as well as databases covering mathematics research were included. Naturally, future studies could include even more databases and try further ways of exploratory search, such as a handsearch of relevant journals (see for example Popham et al. (2018)). However, it needs to be noted that in the current review, only two of the articles included in the final sample were identified through exploratory searches, more specifically, through searching the references of articles identified through the database search. Futhermore, no clear supremacy of specific journals was found and those identified as somewhat more relevant due to publishing two reviewed articles were all abstracted, respectively indexed in at least one of the databases searched.

Finally, the current study provided only a description of the current state of research in the field of interest, summarizing the reviewed articles with regard to several aspects such as theories framing research and drawing tentative conclusions based on the findings of the studies in their entirety. Conducting a meta-analysis was not deemed appropriate, since such an endeavor requires a precise research question detailing for example specific outcomes of interest (see also Liberati et al., 2009). However, the aim of the author was to give an overview on *all* available research in the broad field of self-regulated learning in mathematics tertiary education. Furthermore, the results showed that studies in this field addressed a broad variety of topics, with not more than one third of studies focusing on the same major category of research questions or hypotheses. This finding strengthened the author's belief that conducting a meta-analysis would not have been appropriate at this point in time. Nonetheless, other researchers are encouraged to conduct a meta-analysis in the future, potentially based on the overview provided in the current review.

3.5.7. **Conclusion**

This review summarized the current state of research concerning self-regulated learning in tertiary mathematics education. It illustrated the diversity of topics examined, theories referred to, definitions constructed, aspects focused on, instruments used and target groups studied. Furthermore, based on the reviewed studies, conclusions about the nature and correlates of self-regulated learning and opportunities to support it could be draw. However, the review also pointed to the existence of various gaps in the literature which should be closed by future studies. In concluding, it is hoped that the present review will be a catalyst for future research on self-regulated learning and a helpful tool for practitioners to orient themselves in the maze of self-regulated learning research.

4. Self-regulated learning of engineering students in tertiary mathematics education: An interview study

Given the importance of mathematics education for engineers on one hand and the relevance of self-regulated learning in tertiary education on the other hand, it seems essential to bring together both areas of research. The relevance of this endeavor is strengthened by the fact that several researchers in the field of self-regulated learning have outlined the importance of adopting a domain- or course-specific and dynamic perspective concerning self-regulated learning (e.g. Boekaerts, 1995; Boekaerts & Corno, 2005; Roth et al., 2016). Thus, in the current study, engineering students' self-regulated learning in a mathematics course at a university of technology in Germany was explored.

Although there is a broad variety of models of self-regulated learning, most of them differentiate among (meta-)cognitive, motivational, affective and behavioral aspects or layers (e.g., Credé & Phillips, 2011; Dent & Koenka, 2016; Panadero, 2017; Zeidner et al., 2000). The present study aimed at covering three of these aspects. More specifically, it focused on students' use and evaluation of various learning offers, their learning strategies, achievement goals and attributions for their exam results as well as the time spent studying in mathematics courses. Learning strategies, achievement goals and attributions are integrated in prominent self-regulated learning theories, for example in the conceptual framework of self-regulated learning developed by Pintrich (Pintrich, 2000b, 2004) and in Zimmerman's (2000) Cyclical Phases of Self-Regulated Learning model. Furthermore, although students' choice and use of learning offers are often not explicitly considered in models of self-regulated learning, several of them point to the importance of students' behavior (e.g., choice of courses) and their perception of and interaction with the learning context (e.g., management of the study environment) (Pintrich, 2000b; Wild & Schiefele, 1994; Zimmerman, 2000). Similarly, self-regulated learning models have also pointed out the importance of time spent studying (e.g. Schmitz, 2001; Schmitz & Wiese, 1999; Schmitz & Wiese, 2006). Taking this into account, students' use and evaluation of learning offers as well as the time they spent studying were understood as behavioral aspects of self-regulated learning in the current study. With respect to all these constructs, to the author's knowledge, only few studies have yet focused specifically on the domain of mathematics education or even more specifically, on mathematics tertiary education for engineering students. The present study sought to enrich respective knowledge and thus, to provide the basis for educational interventions with the overall aim to support engineering students as they pass through their mathematics education at university. The following chapter provides an overview of relevant previous theoretical and empirical findings, based on which the research questions for the current study are derived.

4.1. Theoretical background

4.1.1. Learning offers

In Germany, typical mathematics courses consist of a lecture held once or twice a week, which is accompanied by tutorials and weekly worksheets with mathematics problems as homework for students (Dahmen & Freyn, 2014; Griese, 2016; Hänze, Fischer, Schreiber, Biehler, & Hochmuth, 2013; Rach & Heinze, 2011). The tutorials are typically taught by teaching assistants, who often are older students (Kürten et al., 2014; Püschl, Biehler, Hochmuth, & Schreiber, 2016; Rach & Heinze, 2011). Similar concepts are reported for other countries such as Norway (Rønning, 2014, 2017), or Mongolia (Davaanyam & Tserendorj, 2015). More recently, these traditional learning offers have been enriched with online resources, for example lecture recordings (Rønning, 2014) and video tutorials (Loch, Gill, & Croft, 2012).

In the following, existing research regarding the use and evaluation of the named learning offers in mathematics tertiary education in general, respectively where available for engineering students in particular, will be presented. However, it will become clear that such research is relatively scarce. Furthermore, only few studies have yet focused on multiple learning offers simultaneously (see Inglis, Palipana, Trenholm, and Ward (2011) for an exception). Thus, important gaps in the literature remain (Hora & Oleson, 2017). The current study aims to contribute to and enhance this body of literature with a special focus on the German educational system.

4.1.1.1. Lectures and tutorials

Attendance rates reported for mathematic lectures for engineering students vary greatly between different studies as well as between different students (Inglis et al., 2011; Jaworski, 2008). For example, Rønning (2014, 2017) found that about 70% of engineering students enrolled in mathematics courses reported attending lectures to a large extent and only about 6% (Rønning, 2014) reported attending them to a little or no extent. Similarly, Roegner and Heimann (2014) found an attendance rate of about 65% in a mathematics course for engineering students. However, Roegner et al. (2016) report that less than one third of students attended a mathematics lecture for engineering students at the end of the semester. And in a study by Inglis et al. (2011) with engineering and mathematics students, mean lecture attendance was 56% for the whole sample, but varied between 31% and 83%, depending on the use of other learning offers.

Research on attendance in tutorials is very scarce. To the author's knowledge, the only study of slight relevance for the current investigation was conducted by Rodgers (2001) and showed a lower absence rate in tutorials compared to lectures in a statistics course for economics and business students. However, this number is difficult to interpret since attendance was recorded in tutorials, but not in lectures. The author further reports that attendance in lectures as well as in tutorials declined over the course of a semester.

Engineering students attend mathematics lectures for various reasons, including communicating with the lecturer and other students, perceiving attendance as an incentive for structured studying, receiving explanations, and salving one's conscience (Rønning, 2017). Furthermore, according to Roegner et al. (2016), reasons why students stop to attend mathematics lectures for engineering students include a too strong focus on theories, failure to follow the lecture and a preference for receiving explanations by tutors. Similar reasons for non-attendance are reported by Sikko and Pepin (2013) and similar reasons for attendance by Cretchley (2005) for students from various degree programs including engineering enrolled in mathematics courses. In line with this, although several studies showed that engineering students value mathematics lecture attendance and believe that it supports learning (Harris & Pampaka, 2016; Rønning, 2014, 2017; Sikko & Pepin, 2013), Harris and Pampaka (2016) report that students also identify problems of lectures, in particular the high pace, focus on proof, rigor and conceptual understanding and lacking opportunities for communication with the lecturer.

Tutorials however, in particular the opportunity to ask questions (Harris & Pampaka, 2016) and the tutor (Roegner & Heimann, 2014) seem to be appreciated thouroughly by engineering students. Roegner and Heimann (2014) report that with respect to tutorials, students appreciate the opportunity to work mathematics problems on their own more than working in groups. Positive attitudes towards tutorials were also found in studies focusing not exclusively on engineering students. For example, Sikko and Pepin (2013) report that students agreed that they benefitted greatly from tutorials and used them to receive help.

4.1.1.2. Lecture recordings

In this study, lecture recordings refer to audio recordings of face-to-face-lectures, which are optionally also coupled with lecture slides, a video of the lecturer etc. (O'Callaghan, Neumann, Jones, & Creed, 2017). Some studies suggest that in general, lecture recordings are used quite intensively in mathematics courses (Gunesch, 2013a, 2013b). For example, Le, Joordens, Chrysostomou, and Grinnell (2010) report that over 90% of students in calculus classes watched lecture recordings at least once. However, for engineering students, Rønning (2014, 2017) found that only about 20% reported an extensive use of lecture recordings and about 17% reported using them only to a little or to no extent in mathematics courses.

Engineering students use mathematic lecture recordings to review contents of the lecture (Rønning, 2014). Similar results have been found in other studies conducted in mathematics courses not specific to engineering students (Gunesch, 2013a, 2013b). In addition, Gunesch (2013a, 2013b) reports that students use lecture recordings for exam preparation. In line with the latter finding, in other disciplines, an increased use of lecture recordings in advance of tests and examinations was found (e.g. Copley, 2007; Rust & Krüger, 2011; von Konsky, Ivins, & Gribble, 2009).

According to studies by Gunesch (2013a, 2013b, 2015), students appreciate mathematics lecture recordings. Furthermore, although a common concern with respect to lecture recordings is that they lead students to stop attending classes (Larkin, 2010; Traphagan, Kucsera, & Kishi, 2010), Gunesch (2013a, 2013b) reports that students used lecture recordings in addition to attending the lecture in person. However, to the author's knowledge, neither this effect nor students' evaluation of lecture recordings in mathematics courses have been investigated specifically for engineering students yet.

4.1.1.3. Video tutorials

An additional online learning offer used in mathematics higher education are video tutorials. Video tutorials explain solutions to mathematical problems. Using screencasts (i.e. recordings of screen movements), the solution to a mathematics problem is written down stepwise, either in handwriting or typeset (Jordan, Loch, Lowe, Mestel, & Wilkins, 2012; Loch et al., 2012) and explained in parallel, using an audio recording coupled with the video (Jordan et al., 2012; McLoughlin & Loch, 2016).

Existing studies do not provide a clear picture on how many engineering students actually use video tutorials in mathematics courses and how often they use them. However, there is initial empirical evidence that video tutorials are a popular learning tool for mathematics courses among engineering students (Anastasakis, Robinson, & Lerman, 2017; Loch et al., 2012). In line with this, several studies examining the use of video tutorials in mathematics courses involving students from different degree programs including engineering found rather intensive use of video tutorials, but also a non-trivial number of non-users (Ahmad, Doheny, Faherty, & Harding, 2013; Kay & Kletskin, 2012).

Reasons why engineering students use video tutorials in mathematics courses are assistance with mathematic problems, difficulties understanding contents and preparation for tests (McLoughlin & Loch, 2016). Similar reasons have been reported for students from various degree programs including engineering enrolled in mathematics courses (Ahmad et al., 2013) and Kay and Kletskin (2012) showed in such a sample that students' use of video tutorials strongly increased in advance of a test. In addition, further reasons for using video tutorials in mathematics courses identified by studies conducted with students from engineering and other disciplines included reviewing contents, making up for contents missed or forgotten, enriching notes taken during the lecture (Ahmad et al., 2013), perceived positive effects on learning (Kay & Kletskin, 2012) as well as the opportunity to receive explanations (Kay & Kletskin, 2012; Ní Shé, Mac an Bhaird, Ní Fhloinn, & O'Shea, 2017) and solutions to mathematics problems (Ní Shé et al., 2017).

Reasons for not using video tutorials found in studies conducted in mathematics courses for engineering and other students included lacking awareness of the offer (Ahmad et al., 2013; Kay & Kletskin, 2012; Loch et al., 2012), lacking time to use the video tutorials (Kay & Kletskin, 2012) and no perceived need to use them due to having understood the contents, for example with the help of other learning offers such as the lecture (Ahmad et al., 2013; Kay & Kletskin, 2012).

Furthermore, regarding the evaluation of video tutorials, these studies showed that students appreciate video tutorials (Ahmad et al., 2013; Kay & Kletskin, 2012; Loch et al., 2012; Ní Shé et al., 2017) and that they value in particular that video tutorials allow them to study when and where as well as as quick as they want to (Ahmad et al., 2013; Loch et al., 2012; Ní Shé et al., 2017), that they offer step-by-step solutions (Ahmad et al., 2013; Loch et al., 2012), are multimodal, provide an experience similar to lecture attendance and support enjoyment of and interest in contents (Ahmad et al., 2013).

4.1.1.4. Homework problems

Even though every mathematics lecturer probably has an opinion about it, empirical evidence concerning the rates of homework completion in mathematics tertiary education is very slim. Dame, MacGillivray, and Edwards (2009) report that in introductory mathematics courses, the mean percentage of graded homework submitted by students ranged between 74% and 88%. The highest percentage was found in a course for students continuing in engineering, science and mathematics.

With respect to perception of homework, existing research suggests that engineering students appreciate homework in mathematics courses (Roegner & Heimann, 2014; Roegner et al., 2016). In line with this, Sikko and Pepin (2013) showed that students from different degree programs including engineering strongly believed that they benefitted from working mathematics problems. Furthermore, Rach and Heinze (2013) report that mathematics students believe that mathematics homework supports learning and understanding, self-regulation and exam preparation, but that students also feel challenged or even overburdened and pressured by homework problems.

4.1.2. Time spent studying

The time students spend studying for courses, is a central topic of discussion among students and lecturers. However, it is very difficult to come to general conclusions about how much time students spend studying for courses in higher education, since existing studies differ concerning important aspects such as the definition of the time spent studying (e.g., whether time spent in formal education is included) and the level of specificity (e.g., whether the time spent for a specific course or for studying in general is assessed). In addition, only few studies have investigated specifically how much time engineering students spend studying for mathematics courses in higher education. Bergsten and Jablonka (2017) found that engineering students reported spending more time for mathematics courses compared to other courses. More specific results are provided by Jaworski (2008), who showed that in a mathematics course for engineering students, the majority of students reported spending two to four hours per week on mathematics besides the two 50-minutes lectures. The other students reported spending even less time. Similarly, Anthony (2000) found that among students enrolled in a first-year mathematics course, more than half reported spending four or less hours per week on mathematics problems and independent study. Less than one fifth reported studying 12 to 13 hours per week. However, it is unclear in which degree programs the students were enrolled. And in a mathematics course for business sciences, Laging and Voßkamp (2016) found that mean time spent for preparation and follow up ranged between about two and four hours for lectures and between about one and a half and four hours for tutorials and mathematics problems.

4.1.3. Learning strategies

To date, only few studies have investigated learning strategies of engineering students in mathematics courses in higher education. There is initial evidence that peers play a central role for engineering students' learning of mathematics (Anastasakis et al., 2017; Griese, 2016). For example, Griese (2016) reports that besides using literature, reaction strategies, and management of effort and the learning environment, peer learning was also used often as a learning strategy by engineering students enrolled in first-year mathematics courses. The importance of peers for learning was also demonstrated by Sikko and Pepin (2013) in a sample of students from different degree programs enrolled in mathematics courses.

Regarding cognitive strategies, Kortemeyer and Biehler (2012) report that, compared to prospective teachers, engineering students made slightly higher use of elaboration strategies, but lower use of memorization strategies in mathematics courses. However, within the sample of engineering students, higher ratings were found for control strategies and effort regulation compared to elaboration and memorization strategies. In line with these findings, Griese (2016) found that among cognitive strategies, engineering students reported higher use of organizational and elaborational as well as metacognitive strategies compared to rehearsal strategies. Furthermore, Rach and Heinze (2011) stress the importance of elaboration strategies overall and self-explanations in particular for mathematics tertiary education.

Researchers have also specifically examined students' learning behavior when working on mathematics problems. The only study known to the author focusing exclusively on engineering students showed that in case of difficulties, engineering students search for examples in the textbook (Rønning, 2017). Furthermore, Griese (2016) claims that engineering students tend to work on mathematics problems together with their peers. Additional evidence is provided by studies investigating learning strategies in mathematics but not specifically for engineering students. These studies showed that students ask peers and use help services in case of difficulties (Anthony, 2000), copy solutions from peers or the internet (Ableitinger, 2012; Liebendörfer & Göller, 2016; Liebendörfer & Hochmuth, 2012; Rach & Heinze, 2013), mimick the procedure from superficially similar tasks from textbooks or other sources (Cifarelli et al., 2010; Lithner, 2003) or use (more or less systematic) trial-and-error strategies (Cifarelli et al., 2010). In line with this, Ní Shé et al. (2017) report that students from various degree programs including engineering enrolled in mathematics courses wanted to be provided with solutions to mathematics problems in order to correct their own work as well as to learn or mimic the procedure.

In addition, there is also initial evidence regarding engineering students' learning strategies for exams in mathematics courses. In particular, prior exams seem to play an important role for exam preparation (Anastasakis et al., 2017). They are used to identify the typical structure of exams and to evaluate understanding. Students also check the time they spend as well as their solutions with the help of prior exams (Anastasakis et al., 2017). Further strategies for exam preparation include identifying relevant content in lecture slides and the workbook and doing many problems (Anastasakis et al., 2017). Furthermore, Kürten et al. (2014) report that memorizing procedures is a common strategy of students from STEM degree programs in mathematics courses.

Little is known about the development of learning strategies over time and existing results are far from consistent. Specifically for engineering students, over the course of one semester Griese, Glasmachers, Härterich, et al. (2011) found a decrease of the use of elaboration, rehearsal and metacognitive learning strategies and Griese (2016) found a decrease of the use of elaboration strategies, rehearsal strategies, effort and literature, whereas attention showed a positive development (i.e. reduced distraction at the end of the semester). In contrast, Kolter, Liebendoerfer and Schukajlow (2016) found a slight (but not significant) decrease of organizational strategies over two semesters but a slight (but not significant) increase of rehearsal strategies in a sample of prospective teachers enrolled in mathematics courses. Moreover, the authors report that elaboration strategies showed a significant decrease over the course of the first semester, followed by a significant increase over the course of the second semester. Schreiber, Bianchy, Biehler, Hänze, and Hochmuth (2011) found an increased use of metacognitive learning strategies over the course of one semester in a sample of prospective teachers enrolled in mathematics courses. However, in a study by Hodges and Kim (2010) conducted in an online college algebra and trigonometry course, no significant change in students' self-reported use of metacognitive self-regulation strategies over the course of the semester was found. Furthermore, following an inverted-classroom-intervention, Talbert (2015), did not observe significant changes in students' self-reported self-regulated learning strategies in a course on mathematical proofs.

Overall, studies concerning learning strategies of engineering students in mathematics courses in higher education are thus relatively scarce. This is particularly critical since recent studies suggest not only the existence of learning strategies that potentially could be specific to the field of mathematics (e.g., Liebendörfer et al., 2014) and domain-specific effects for learning strategies in general (Dent & Koenka, 2016; Greene et al., 2015; Rotgans & Schmidt, 2009), but also that there are differences between students from different degree programs concerning the use of learning strategies in mathematics courses (Göller et al., 2013;

Kortemeyer & Biehler, 2012). The current study can contribute to improve this situation and also reacts to calls to investigate the development of learning strategies in higher education (Credé & Phillips, 2011).

4.1.4. Achievement goals

Initial evidence about engineering students' goals in mathematics courses is provided by Anastasakis et al. (2017). The author reports that second year engineering students' most important goal with respect to mathematics courses was achieving a good mark. Other important goals were passing the course, acquiring mathematical skills and understanding mathematics or its application. In a sample of students from various degree programs enrolled in first-year mathematics courses, Kaldo and Reiska (2012) found that students rated mastery goals (i.e. striving to learn and to achieve understanding) higher than performance-approach goals (i.e. striving to look smart in front of others and demonstrate one's competence). Furthermore, Cano and Berbén (2009) identified four different profiles of achievement goals among first-year university students from different disciplines enrolled in mathematics courses. The clusters were characterized by a) low achievement goals with particularly low mastery-approach goals b) low achievement goals except for mastery-approach goals, c) high achievement goals except for performance-approach goals and d) high achievement goals in general and particularly high performance-approach goals.

Similarly, there is a void in the literature concerning the development of achievement goals over time in mathematics tertiary education. To the author's knowledge, the only existing study was conducted in a mathematics course for prospective teachers and found a significant decrease of performance-avoidance goals over the course of the semester (Schreiber et al., 2011). This is in line with studies from other disciplines suggesting that achievement goals are relatively stable but also amenable to change (Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013). For example, Fryer and Elliot (2007) found substantial rank-order stability of students' achievement goals in introductory psychology courses, but also important changes at the level of individual students as well as at the sample level. At the sample level, a decrease of mastery-approach goals, and an increase of performance-avoidance goals were found. For performance-approach goals and mastery-avoidance goals, analyses at the individual level showed that equal proportions of participants showed increases and decreases over time.

The lack of research concerning students' achievement goals in mathematics tertiary education is especially critical in the light of studies demonstrating that achievement goals are domain-specific (Bong, 2001; Sparfeldt et al., 2007). Furthermore, considering that recent meta-analyses on achievement goals identified the nationality of the sample as a significant moderator of the relationships among achievement goals and with performance outcomes (Huang, 2012; Hulleman et al., 2010), a further limitation of existing research on achievement goals is the strong prevalence of studies conducted in North America (Huang, 2012; Hulleman et al., 2010). Also, there is increasing awareness that the conceptualization and measurement of achievement goals influences research results (Huang, 2012; Hulleman et al., 2010). Given the broad range of theoretical models concerning achievement goals, qualitative approaches have been suggested as especially well-suited to investigate achievement goals free from the boundaries imposed by instruments developed based on specific theories (Lemos, 1996; Urdan & Mestas, 2006). Thus, by using a qualitative approach to investigate engineering students' achievement goals specifically for mathematics courses in

Germany, the current study aimed to make important contributions to achievement goal research.

4.1.5. Attributions

Existing research shows that in mathematics higher education, important causes of achievement as identified by students include effort (Anthony, 2000; Maidinsah, Embong, & Wahab, 2014; Pyzdrowski et al., 2013; Schutz, Drogosz, White, & Distefano, 1998), motivation, quality of teaching, especially communication skills of the instructor, doing homework or completing assignments, and (seeking as well as the availability of) help and support (Anthony, 2000; Pyzdrowski et al., 2013). Among these, effort seems to be an especially important factor (Anthony, 2000; Maidinsah et al., 2014).

In addition, several studies have investigated differences concerning attributions for success and failure in mathematics higher education. In a study by Cortés Suárez (2004), an analysis of students' open-ended statements about the causes of their test performance in a mathematics course showed that for both high and low achieving students, effort was most commonly identified as a cause of performance, followed by ability for students with higher grades and ability and task difficulty for students with lower grades. Similarly, Anthony (2000) found differences between students passing or failing a mathematics course concerning the influence on success and failure they ascribed to various factors. Students passing the course rated aspects of teaching (e.g., presentation style) and their own learning behavior (e.g., working mathematics problems) as more influential for success compared to unsuccessful students. Moreover, they rated the importance of focusing on understanding respectively on rote learning higher for success respectively failure. Failing students rated factors beyond their control (e.g., time overload) as more important for failure.

Again, it is obvious that there are only few studies with a specific focus on mathematics tertiary education and only one of them (Pyzdrowski et al., 2013) included engineering students. This is especially critical since results from the school context suggest that attributions might be (at least in part) domain-specific (Boekaerts et al., 2003). Similarly, none of the studies cited above was conducted in Germany, while at the same time, there is initial evidence that nationality or culture might have an impact on attributions made, respectively attributional biases (Mezulis et al., 2004). The current study aims to enrich the research field by exploring engineering students' attributions for their exam results in mathematics courses in tertiary education using a qualitative approach. Furthermore, previous attribution research has mostly focused on attributions for failure (Platt, 1988). The current study however examined not only students' exam results but also their satisfaction with these results and thus allowed to examine perceived causes of subjective success and failure.

4.2. Research questions

The aim of this study was to explore and descibe (meta-)cognitive, motivational, and behavioral aspects of engineering students' self-regulated learning in mathematics courses at university level. The study was guided by 10 research questions, which are outlined below, including respective expectations based on previous research. Furthermore, Figure 11 visualizes the topics that the research questions addressed.

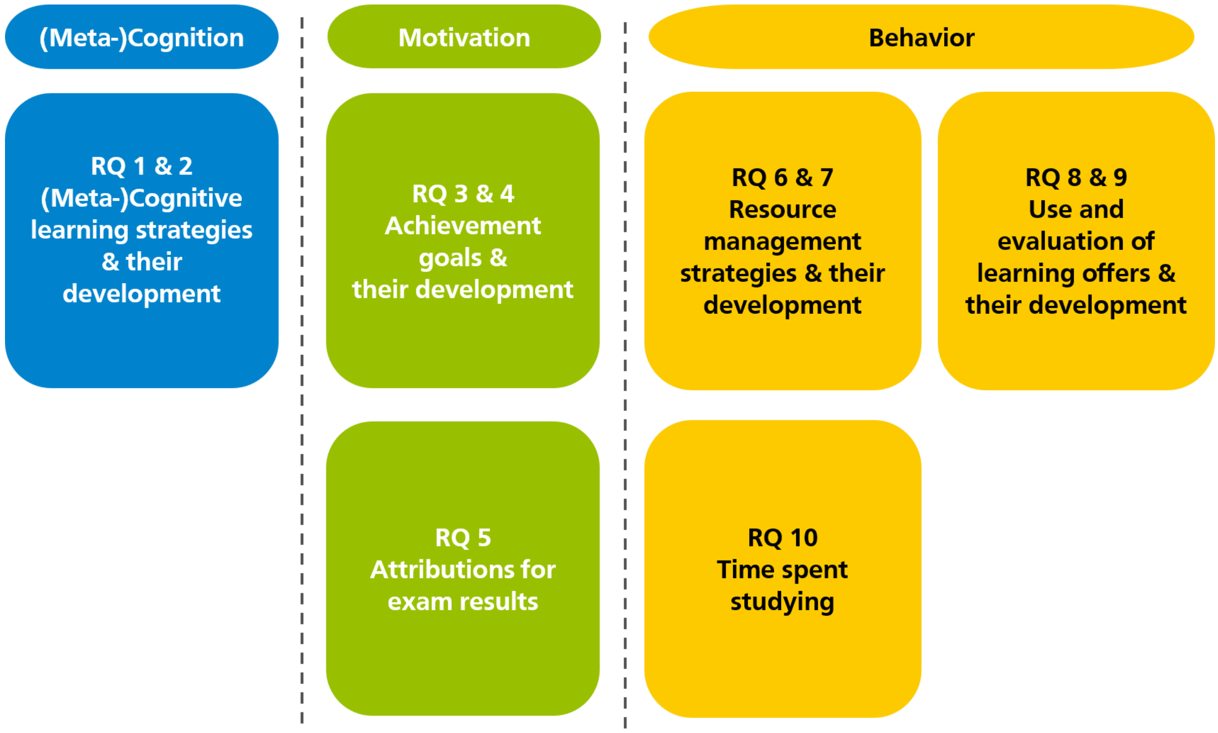

Figure 11. Topics addressed by the research questions guiding the study. RQ = Research question.

1. What are important (meta-)cognitive learning strategies for a) working mathematics problems and b) exam preparation?

Based on previous research (Anastasakis et al., 2017; Griese, 2016; Kortemeyer & Biehler, 2012), it was assumed that metacognitive strategies would be important in both situations. Furthermore, it was expected that elaboration strategies would be important especially for working mathematics problems (Rønning, 2017) and rehearsal and organizational strategies (Anastasakis et al., 2017) for exam preparation.

2. How does use of (meta-)cognitive learning strategies for a) working mathematics problems and b) exam preparation change over the course of study?

With respect to working mathematics problems and exam preparation, based on previous research (Griese, 2016; Griese, Glasmachers, Härterich, et al., 2011), a decrease in elaboration, rehearsal and metacognitive strategies was expected.

3. Which achievement goal patterns can be identified?

Based on previous research (Cano & Berbén, 2009), it was assumed that students would adopt multiple goals. Furthermore, it was assumed that outcome goals and mastery-approach goals as well as passing the course and understanding the application of mathematics would emerge as important goals (Anastasakis et al., 2017).

4. How do achievement goal patterns change over the course of study?

Based on previous research (Schreiber et al., 2011), changes in achievement goals, in particular a decrease in performance-avoidance goals, were expected.

5. What are important attributions for exam results?

Based on previous research (Anthony, 2000; Maidinsah et al., 2014; Pyzdrowski et al., 2013; Schutz et al., 1998), it was assumed that effort, motivation, teaching quality, homework completion, and availability and use of help and support would emerge as important attributions. Furthermore, based on previous research (Anthony, 2000; Cortés Suárez, 2004) it was expected that internal causes would be cited more often when explaining success, whereas external causes would be cited more often when explaining failure.

6. What are important resource management strategies for a) working mathematics problems and b) exam preparation?

Based on previous research (Anastasakis et al., 2017; Griese, 2016; Kortemeyer & Biehler, 2012; Rønning, 2017), it was assumed that effort regulation, social strategies, management of the learning environment and use of literature would emerge as important resource management strategies. In particular, peer learning (Anastasakis et al., 2017; Griese, 2016) and textbooks (Anastasakis et al., 2017; Rønning, 2017) were expected to play an important role for both situations, whereas prior exams and lecture slides (Anastasakis et al., 2017) were expected to be especially important for exam preparation.

7. How does use of resource management strategies for a) working mathematics problems and b) exam preparation change over the course of study?

Based on previous research (Griese, 2016), a decrease of literature and effort management as well as of attention problems was expected.

8. What are important learning offers and how are they used?

Based on previous research, it was assumed that tutorials (Harris & Pampaka, 2016; Roegner & Heimann, 2014), homework (Dame et al., 2009; Roegner & Heimann, 2014; Roegner et al., 2016) and video tutorials (Anastasakis et al., 2017; Loch et al., 2012) would emerge as important learning offers, as indicated by frequency of use and/or evaluation. Tutorials were expected to be used for asking questions (Harris & Pampaka, 2016) and working mathematics problems (Roegner & Heimann, 2014). Expected reasons for use of video tutorials were working mathematics problems, comprehension difficulties and exam preparation (McLoughlin & Loch, 2016). For lectures, concerning frequency of use and evaluation, ambivalent results were expected (Harris & Pampaka, 2016; Roegner & Heimann, 2014; Roegner et al., 2016; Rønning, 2014, 2017). Expected reasons to attend lectures were communication with lecturer and peers, explanations, a good conscience, and stimulation of learning (Rønning, 2017). Expected reasons for non-attendance were a preference for tutorials, dislike of a strong theoretical focus, problems following the lecture and lacking communication opportunities (Harris & Pampaka, 2016; Roegner et al., 2016). Lecture recordings were assumed to play a minor role but to be used for reviewing lecture contents (Rønning, 2014, 2017).

9. How does use and evaluation of learning offers change over the course of study?

Based on previous research, it was assumed that use of lectures and tutorials would decrease within semesters (Rodgers, 2001), whereas for lecture recordings (Copley, 2007; Rust & Krüger, 2011; von Konsky et al., 2009) and video tutorials (Kay & Kletskin, 2012), an increase before the exams was expected. For homework, due to a lack of respective research, no assumptions could be made concerning the development over time.

10. How much time do students spend studying?

Based on previous research (Jaworski, 2008), it was assumed that students would spend up to six hours per week studying.

4.3. Method

In this section, the sample, the process of data collection and the measurement instruments, i.e. the interview guideline and the questionnaire are described. The section concludes with a detailed description of the process of analyzing the data from interviews and questionnaires.

4.3.1. Participants

The study was conducted at a university of technology in Germany. Participants were recruited with the help of student assistants in a mathematics course, which was mainly offered for engineering students in their third semester. The course consisted of a lecture held twice a week and tutorial groups. Students were informed about the study in the tutorial groups and online via a learning platform. When students interested in participating in the study contacted the author, they were informed about the background, goals, content and procedure of the study as well as about the measures to ensure privacy protection and their rights as participants. Participants received a 15-Euro-voucher for an online shop as an incentive for their participation in the study. This incentive is comparable to those provided in other interview studies (e.g. Hora & Oleson, 2017).

Overall, 28 students participated in the study. However, one participant had to be excluded from the final sample due to not being an engineering student. Thus, the final sample used for analysis consisted of 27 students. Of those, 77.78% were male (n = 21) and 22.22% female (n = 6). The age of participants ranged from 18 to 29 (M = 21.48, SD = 2.46). All students were enrolled in degree programs of engineering faculties at the university and the majority (n = 19, 70.37%) was in their third semester (range one to five). The last grade received in mathematics ranged from 6 to 15 points, with about half of participants (n = 14, 51.85%) reporting that they had received 13 to 15 points, which can be categorized as very good. 11.11% (n = 3) of participants reported that they had achieved their university-entrance diploma in another country. The great majority of students (n = 22, 81.48%) had taken three mathematics courses during their career in higher education, including the current course, while the others (n = 5, 18.51%) had already taken four or five courses. Grades received in these courses ranged from excellent to failing.

The gender ratio was similar to that of alumni of engineering faculties of the university where research was conducted, to that of mathematics courses for engineering students at other German universities of technology (Griese, 2016), and to the overall gender ratio among engineering students in Germany according to data from the German Federal Statistics Office (Statistisches Bundesamt (Destatis), 2017). Students' marks in mathematics in school were somewhat higher than those reported for mathematics courses at another German university of technology (Griese, 2016), although the results are difficult to compare. Participants in the current study were on average slightly older than the engineering students enrolled in first-year mathematics courses studied by Griese (2016), which is plausible given that the majority was already in the third semester. The proportion of students who had achieved their university-entrance diploma in another country was higher than among alumni of engineering faculties of the university in general, but lower than among engineering students in Germany according to data from the German Federal Statistics Office (Statistisches Bundesamt (Destatis), 2017).

4.3.2. Procedure

The typical procedure was as follows: First, participants were welcomed. They were offered candy and something to drink and small talk was made to create a confidential atmosphere. Then, the interviewer informed participants about the background, goals, content and procedure of the study, the measures to ensure privacy protection and their rights as participants. Following this introduction, participants received an explanation of the study containing this information in writing. After they had read the explanation, participants signed a consent form. Subsequently, the interview was conducted. After the interview was finished, participants were handed the questionnaire. Finally, the interviewer explicitly thanked participants for their participation. They received the voucher as well as a business card with the contact details of the interviewer. This allowed them to contact the interviewer in case of questions after the examination.

Time and location of the interviews were coordinated with the participants as suggested by Howitt and Cramer (2014). However, all interviews were conducted at university. All interviews were led by the author of this dissertation. Interviews were recorded using an audio recorder. The audio recordings of the interviews had a mean duration of 25 minutes and 55 seconds (range 15 minutes, 45 seconds to 43 minutes, 3 seconds). The overall examination (interview and questionnaire completion) took about 5 to 10 minutes longer.

4.3.3. Measurements

4.3.3.1. Interview guideline

The guideline for conducting the interviews was developed based on the recommendations of Helfferich (2009) and Gläser and Laudel (2010). Following a principle suggested by Helfferich (2009), construction of the guideline was initiated by collecting all questions which were considered to be potentially interesting and relevant based on existing theoretical and empirical research. Particularly, a German adaption of the SRLIS by Spörer (2003) and the model by Helmke and Schrader (2006) for the analysis of effects of teaching provided a valuable basis for development of questions. After narrowing the focus of the study and defining the research questions more precisely, the collected questions were examined closely and unsuitable questions were excluded. Criteria for exclusion of questions were lacking fit with research questions, inappropriate level of abstraction or lacking potential to evoke open and unexpected answers. The remaining questions were sorted by content. Wording of questions was reviewed with regards to the theoretical background and understandability.

Alternative formulations were juxtaposed. Again, questions that were judged as too specific or too abstract were excluded. In a next step, a structure for the guideline was developed based on the research questions. As some questions asked for more specific information than others, they were assigned to different levels. The questionnaire was reviewed and optimized several times with regards to its structure, content and wording.

The final guideline contained five main questions, which were each complemented by additional, more detailed questions (see appendix 7.4). Questions A2 and A3 and their consecutive questions were adapted from Spörer (2003) and for question B1 and its consecutive questions, the model by Helmke and Schrader (2006) provided orientation. The questions referred to students' use and evaluation of various learning offers, their learning strategies for working mathematics problems and exam preparation and their goals in mathematics courses. With respect to these aspects, perceived changes over the course of study were also enquired. Further questions referred to the time spent studying as well as to students' perception of their learning success in general and to their exam results and their respective satisfaction in particular. Lastly, students were asked about the causes they ascribed their exam results to. At the end of the interview, interviewees were given the chance to add important information not covered in the interview.

4.3.3.2. Questionnaire

The questionnaire (see appendix 7.5) was put together by the author specifically for the current study. It asked for participants' age, gender, degree program and semester. Furthermore, it contained questions concerning students' performance in mathematics, in particular their last grade in school, the mathematics courses taken during their studies and their grades in these courses. All questions were open-ended and thus, allowed to assess students' diversity as accurately as possible.

4.3.4. Data analysis

4.3.4.1. Interview data

The audio recordings of the interviews were transcribed verbatim and anonymized in the process by the author of this dissertation using the software f4transcript. The transcription rules suggested by Dresing and Pehl (2015) and Kuckartz, Dresing, Rädiker, and Stefer (2008) were used in slightly adapted form. Each transcript was checked twice. Anonymized interview transcripts were analyzed using the software MAXQDA 2018. A method for qualitative content analysis described by Kuckartz (2016) provided orientation for the method of analysis, which was conducted in the following steps:

1) Main categories were developed based on the research questions and the guideline for the interviews. For learning strategies, the LIST questionnaire developed by Wild and Schiefele (1994) and its revision specific to mathematics courses by Liebendörfer and colleagues (Göller et al., 2013; Liebendörfer, 2017; Liebendörfer et al., 2014) provided orientation for the development of categories and their definition.

2) All transcripts were read thoroughly. Interesting, difficult and unclear passages were marked with colors. For each interview, a short summary was created based on the research questions, which was added to the transcript as a memo. Furthermore,

special characteristics noticed, e.g. with respect to the course of the interview, were documented as well.

3) Three texts were coded using the initial coding frame. After each coding, the coding frame was revised.

4) All interview transcripts were coded with the revised coding frame. Interviews were read line by line and passages were assigned to categories. No specific restrictions were made regarding the minimum or maximum length of the codings. Multiple coding of passages was possible. Initially, seven randomly selected transcripts (= 25.93% of all transcripts) were coded sequentially by a second coder besides the author of this dissertation. For each transcript, coders compared their codes and deviations were discussed and resolved. If deemed necessary, the coding frame was adapted. The remaining 20 transcripts (including those which had been coded during the test of the initial coding frame) were only coded by the author of this dissertation.

5) All categories were reviewed with respect to the need for (further) subcategories. Where subcategories were deemed to be necessary, coded interview passages were reread, summarized and ideas about potential subcategories were generated, also based on previous research (especially the learning strategies developed by Liebendörfer and colleagues (Göller et al., 2013; Liebendörfer, 2017; Liebendörfer et al., 2014)). Then, the most suitable subcategories were selected and integrated into the coding frame. Furthermore, where the inspection of the codings revealed that other categories applied as well and had not been coded in the first round, this was noted as well.

6) The subcategories were used to re-code all interview passages, which had originally been coded with the respective main category. For the categories containing information about the frequency of students' use of learning offers and the perceived helpfulness of these learning offers, evaluative subcategories were defined. For these categories, the author of this dissertation decided on the most appropriate coding together with a second coder. Moreover, codings that had been missed during the first round of coding were assigned as well.

7) After assigning the codings to the subcategories, the whole coding frame and the codings assigned to each category were checked multiple times to ensure the quality of the analysis.

4.3.4.2. Questionnaire data

Questionnaire data was analyzed descriptively. To assess the representativeness of the sample, the results were compared with statistics about engineering education in Germany and data from the university where research was conducted (see section 4.3.1).

4.4. Results

The current study explored engineering students' self-regulated learning in mathematics courses in higher education. More specifically, 10 major research questions guided the study, which focused on (meta-)cognitive, motivational, and behavioral aspects of students' self-regulated learning and their temporal development (see Figure 11). In the following, the results with respect to these research questions will be presented.

Although presenting verbatim citations is common when reporting results in qualitative research, it was deemed inappropriate in the current study due to the fact that the interviews were conducted in German. Thus, verbatim citations in the true meaning of the word would have to be presented in German and thus, would be incomprehensible to those readers not able to speak German and inconsistent with the remainder of the dissertation. Translating the citations into English however would mean that they would no longer be true verbatim citations. Thus, after careful consideration, it was decided to resign from presenting verbatim citations in the following sections. Furthermore, it was decided to display only results for (sub-)categories in which codings for more than one participant were available. This decision was made since the aim of the current study was to identify commonalities between students based on their individual descriptions. Still, the deductive-inductive coding process did acknowledge students' individuality: In most analyses, several levels of subcategories were created, which thus preserved the specific input of the individual students to a large extent.

4.4.1. (Meta-)Cognition

Students' (meta-)cognitive learning strategies were examined for two specific situations: when working on a mathematics problem and when preparing for a mathematics exam. A priori, categories were defined based on the learning strategies proposed by Wild and Schiefele (1994) for (higher) education in general and by Liebendörfer and colleagues (Göller et al., 2013; Liebendörfer, 2017; Liebendörfer et al., 2014) for mathematics tertiary education in particular. Analysis of the codings assigned to each category led to the creation of subcategories and the addition of new learning strategies but the overall structure did not need to be reconsidered.

Table 12

General (meta-)cognitive learning strategies reported by students for different situations

	Exam preparation		**Mathematics problems**	
Learning strategy	***n***	%	***n***	%
Elaboration strategies	9	33.33	18	66.67
Metacognitive strategies	27	100.00	19	70.37
Organizational strategies	20	74.07	4	14.81
Rehearsal	27	100.00	4	14.81
Trying different approaches			3	11.11
Understanding theory	3	11.11		

Note. Reported are only results with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy was reported at least once.

Table 12 shows the frequency with which the main categories for (meta-)cognitive learning strategies for mathematics problems and exam preparation were reported. Complete tables including all levels of subcategories can be found in appendix 7.6 (Table 22 and Table 23). Besides the strategies defined in advance due to theoretical considerations, two other strategies emerged. The strategy "understanding theory" included attempts to understand theoretical contents during exam preparation. The category "trying different approaches" comprised reports by students about repeated attempts to solve a mathematics problem using different methods or problem-solving strategies. It can be seen from Table 12 that differences between mathematics problems and exam preparation were particularly pronounced for cognitive strategies. Whereas rehearsal and organizational strategies were used to a distinctly greater extent during exam preparation, elaboration strategies played a more important role when working on mathematics problems.

The subcategories created inductively provided insight into the specific character of students' learning strategies and showed further differences concerning the cognitive strategies used for the two situations (see Table 22 and Table 23 in appendix 7.6). For instance, using examples was the most prevalent elaboration strategy, both when working on mathematics problems and when preparing for exams. It needs to be noted that these examples were not generated by students themselves but were existing examples, for example those provided by instructors. However, the elaboration strategy of making connections with existing knowledge, for example knowledge from the lecture or tutorial, was mentioned only with respect to mathematics problems. With respect to organizational strategies, the analysis of subcategories also showed specific strategies for specific situations. Creating summaries (especially a formulary) and identifying important contents through search of learning resources or while working mathematics problems were common organizational strategies used during exam preparation. When working on mathematics problems during the semester however, the explicit identification of the task emerged as the only specific organizational strategy. Rehearsing was cited by students mainly with respect to exam preparation. Only for exam preparation, a variety of different ways of rehearsing emerged, for example re-working mathematics problems students had already worked during the semester or solving old exam problems. Furthermore, two other types of rehearsal strategies emerged only for exam preparation: Repetition of contents and repeated use of learning resources. However, compared to rehearsing, these strategies were of minor importance.

Concerning metacognitive strategies, results (see Table 22 and Table 23 in appendix 7.6) showed that for both exam preparation and working mathematics problems, planning was reported by the most students, followed by controlling and reacting. Students' plans referred to the scope, procedure and sequence of learning. Furthermore, for mathematics problems, students also reported analyzing the task and making plans concerning the best point in time to work on them. To control their solutions to mathematics problems, students made use of various resources (most commonly peers). During exam preparation, assessing comprehension and learning, but also comparing and correcting mathematics problems and solving problems under time pressure or test conditions were control strategies reported by students. Students reacted by adapting or keeping up their learning strategies and behavior, using resources or (re-)working mathematics problems.

Furthermore, changes in (meta-)cognitive learning strategies were also examined. As can be seen from Figure 12, only changes referring to exam preparation could be found, the most commonly reported change being an increase in the use of metacognitive strategies. It needs to be kept in mind though that each student was interviewed only once. Thus, changes were reported by students in retrospect.

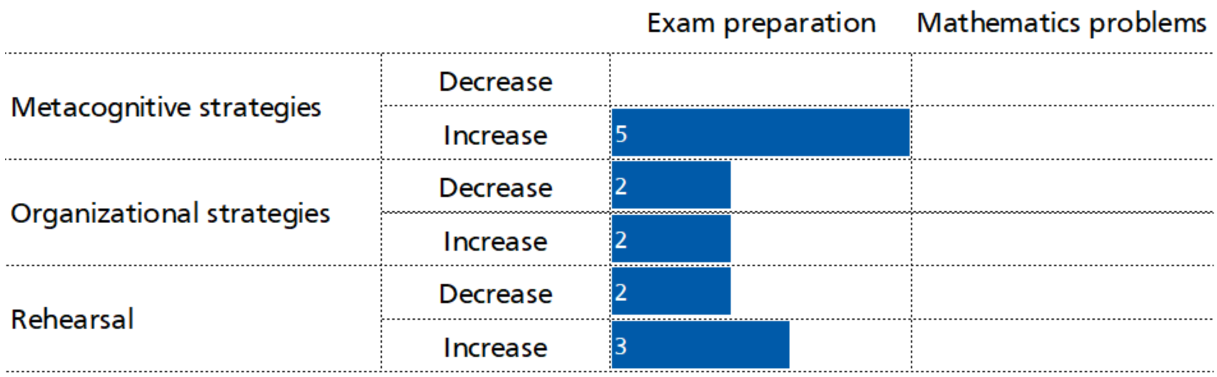

Figure 12. Changes concerning the use of (meta-)cognitive learning strategies reported by students for different situations. Displayed are the number of transcripts *n* in which a change was reported at least once; only learning strategies with *n* > 1 are displayed.

4.4.2. Motivation

The current study focused on two motivational aspects of self-regulated learning. It explored students' achievement goals (including their perceived change over the course of study) as well as students' attributions for exam results.

4.4.2.1. Achievement goals

For achievement goals, no subcategories were defined a priori. Inductive generation of subcategories based on codings revealed three major categories: knowledge-, exam- and application-related goals. The most common goal type were exam-related goals, which were reported by 20 students, followed by application-related goals (n = 16) and knowledge-related goals (n = 10). Knowledge-related goals were characterized by a focus on acquiring knowledge, understanding of contents or scientific thinking skills. Exam-related goals included striving to pass the course and thus, to fulfil one's obligations (n = 17), to achieve a good grade (n = 8), better results than other students (n = 3) or a mediocre or unspecific grade (n = 2). Application-related goals included a focus on acquiring knowledge, understanding or skills in order to be able to apply them in general (n = 6), during one's studies (n = 12) or future career (n = 4).

The majority of students (n = 18) reported more than one goal, with seven students reporting two goals, seven reporting three goals and four reporting more than three goals. Nine students reported only one goal. Of these, two adopted an application-related goal, three an exam-related goal and four a knowledge-related goal. The most common combination was adopting exam- and application related goals (n = 9), followed by exam-application-knowledge (n = 4) and exam-knowledge (n = 2) goal combinations. No student reported a combination of application- and knowledge-related goals without also referring to exam-related goals. When considering the specific subcategories, very individual goal combinations were found, ranging from two goals to six goals. Indeed, the only goal patterns that were shared by more than two students were those characterized by an exclusive focus on one exam- or knowledge-related goal.

11 students reported that their goals had changed during their course of study, whereas 12 students had not experienced a change. Again, it needs to be noted that the development over time was reported by students retrospectively. Four students reported changes within exam-related goals, more specifically either a shift from striving to pass the course to (also) aiming to achieve a good grade ($n = 2$), or from aiming to achieve a good grade to (just) striving to pass the course ($n = 2$). The most common trend was a change from (just) aiming to pass the course to (also) pursuing application-related goals, which was reported by five students. Furthermore, two students reported specific changes of goals, which could not be subsumed under a more general meaningful category and are thus not described further. Three students' answers to the question how their goals had changed over the course of their studies could not be categorized, because they referred to more general motivational issues instead of the goals that had been developed inductively in the current study. In addition, for one student, information regarding the perceived development of goals over the course of study was lacking because the respective question had not been posed by the interviewer.

4.4.2.2. Attributions

Students identified a wide variety of causes of their exam results, which could be assigned to subcategories inductively. All students cited at least one cause. Table 13 demonstrates the main causes perceived by students as influencing their exam results. The most often cited causes were instructors and effort, followed by learning offers. The least important cause were peers. Furthermore, from Table 24 in appendix 7.6, which contains all subcategories created, it can be seen, for example, that among learning offers, tutorials were the most often cited cause and among instructors, the most often cited cause was the professor.

As can be seen from the interview guideline (see appendix 7.4), the interviewer asked students explicitly about the influence of certain aspects (including learning offers and instructors), if they did not mention them spontaneously. Therefore, an additional analysis was conducted, in which only those causes were analyzed, which had been mentioned by students spontaneously (i.e. either completely without instruction by the interviewer or when being asked in general about the perceived causes of their exam results). As can be seen from Figure 13, in this analysis a different picture emerged compared to the analysis in which all causes mentioned were considered. Instructors and learning offers were cited relatively seldom spontaneously. However, effort was still the most often cited cause, followed by learning behavior and peers were still the least cited cause.

In addition, it was also coded whether students mentioned a cause with respect to perceived success or failure, respectively, whether they believed the cause had had a positive or negative effect. The results (see Figure 14) showed that for the majority of causes, positive effects were reported more often than negative effects. The difference was particularly defined for instructors and learning offers. However, for some factors, a diverging (yet plausible) picture emerged, with either a prevalence of reports in relation to failure or negative effects (e.g., exam construction) or a nearly equal relation to success or positive effects and failure or negative effects (e.g., motivation).

Table 13

Factors influencing exam results as perceived by students

Main Category	*n*	%
Ability / knowledge / comprehension	9	33.33
Available time for learning	6	22.22
Effort	24	88.89
Exam behavior	8	29.63
Exam construction	10	37.04
Instructors	24	88.89
Learning behavior	14	51.85
Learning offers	22	81.48
Luck	5	18.52
Motivation	11	40.74
Nervousness	5	18.52
Peers	2	7.41

Note. Reported are only categories with $n > 1$; n = number of transcripts in which a category was reported at least once; % = percentage of overall transcripts in which a category was reported at least once.

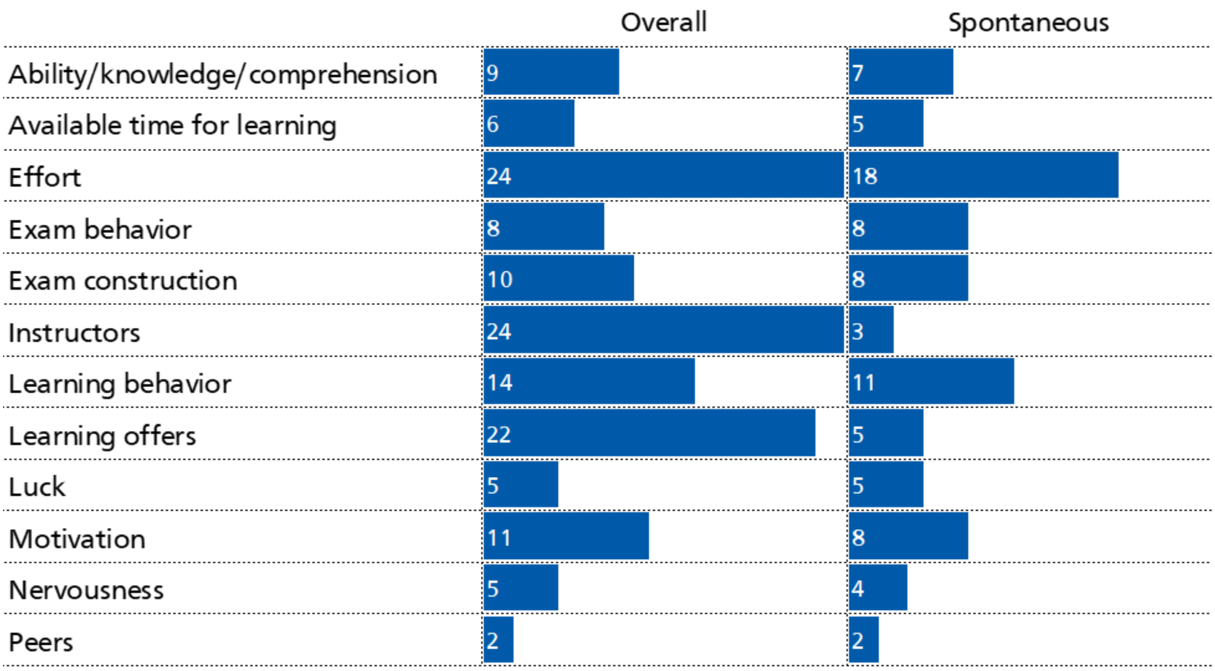

Figure 13. Comparison of main factors influencing exam results cited by students overall or spontaneously. Displayed are the number of transcripts n in which a category was reported at least once; only categories with $n > 1$ are displayed.

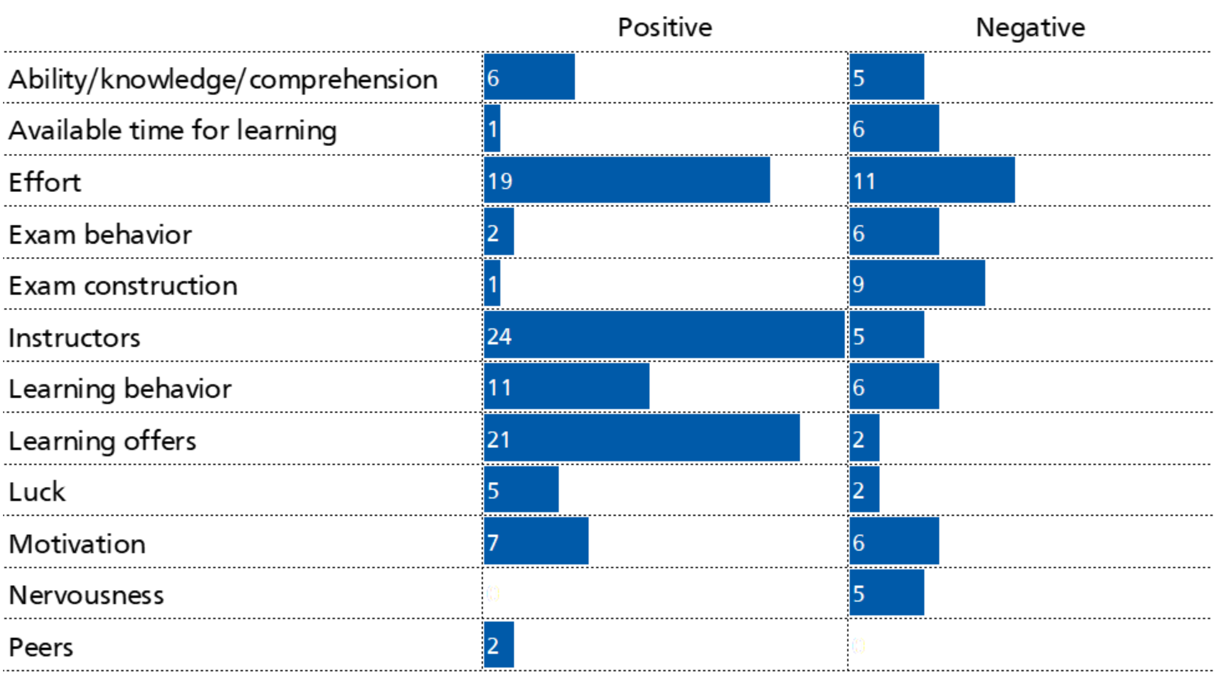

Figure 14. Comparison of main factors cited by students as causes of success or failure, respectively as having a positive or negative effect. Displayed are the number of transcripts n in which a category was reported at least once; only categories with $n > 1$ are displayed.

4.4.3. Behavior

The current study examined three different behavioral aspects of self-regulated learning: Students' resource management strategies, their use of learning offers and the time students spent studying for mathematics. In addition, with respect to the first two aspects, developments over the course of study as perceived by students were also explored.

4.4.3.1. Resource management strategies

Students' resource management strategies were examined for two specific situations: when working on a mathematics problem and when preparing for a mathematics exam. A priori, categories were defined based on the learning strategies proposed by Wild and Schiefele (1994) for (higher) education in general and by Liebendörfer and colleagues (Göller et al., 2013; Liebendörfer, 2017; Liebendörfer et al., 2014) for mathematics tertiary education in particular. Analysis of the codings assigned to each category led to the creation of subcategories and the addition of some new learning strategies but the overall structure did not need to be reconsidered. Table 14 shows the frequency with which the use of resource management strategies was reported. Main categories developed inductively based on students' responses were "copying" (i.e. copying of solutions to mathematics problems from friends and peers), "motivation" (i.e. methods for keeping up one's motivation when working on mathematics problems) and "working alone" (i.e. attempting to solve mathematics problems or to learn on one's own). It can be seen from Table 14 that social strategies and literature were important strategies used by the great majority of students both when working on mathematics problems and when preparing for exams. In addition, students mentioned effort-related issues very often with respect to both situations. Pronounced differences between situations were found especially for study environment, time management, and working alone.

Table 14

General resource management strategies reported by students for different situations

Learning strategy	Exam preparation *n*	Exam preparation %	Mathematics problems *n*	Mathematics problems %
Copying			5	18.52
Effort	25	92.59	26	96.30
Literature	26	96.30	24	88.89
Motivation			2	7.41
Social strategies	25	92.59	27	100.00
Study environment	7	25.93	25	92.59
Time management	25	92.59	14	51.85
Working alone	6	22.22	15	55.56

Note. Reported are only categories with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy was reported at least once.

Inspection of the subcategories created inductively (see Table 22 and Table 23 in appendix 7.6) provide further insight into the characteristics of students' resource management strategies. Friends and peers were important social resources used by a majority of the sample both for exam preparation and when working on mathematics problems. For example, students referred to friends and peers in case of difficulties, questions or need of help, but also reported working on mathematics problems together and comparing and discussing solutions. Furthermore, students reported using a broad variety of learning offers as social support. The learning offers led by student tutors were used frequently, especially in case of difficulties. For exam preparation, the most important learning offer were office hours of student tutors, whereas for mathematics problems, tutorials were most important, followed by office hours of student tutors. Furthermore, when working on mathematics problems, learning offers (most importantly, tutorials) were reported not only as a source for social assistance, but also as a study environment. With respect to effort, students reported high degree of effort for both exam preparation and mathematics problems, however, more students reported lacking effort with respect to mathematics problems. During exam preparation, students' effort was mostly characterized by working many mathematics problems, preparing for the exam already during the semester and high investment of time. For mathematics problems, effort was also characterized not only by working them (e.g., regularly or all problems assigned) but also by high investment of time, by attendance of (multiple) learning offers, for example of more than one tutorial per week, and by persistence in the face of difficulties. Important literature for both situations were lecture slides, video tutorials and mathematics problems and solutions. Concerning time management, students reported both attempts to plan their time as well as problems with time pressure and limited time. Concrete planning of time was reported more often with respect to exam preparation compared to working mathematics problems.

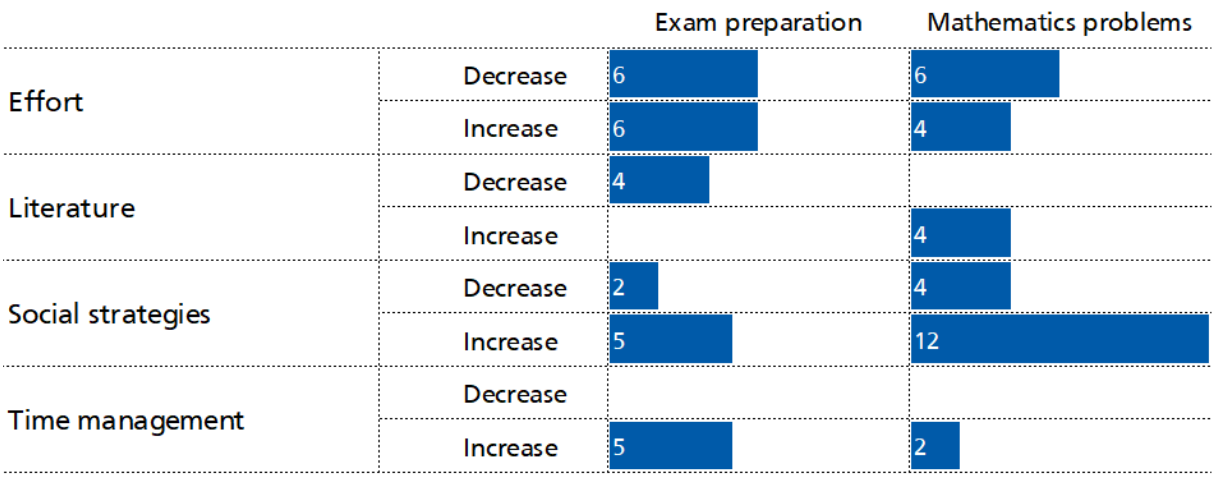

Figure 15. Changes concerning the use of resource management strategies reported by students for different situations. Displayed are the number of transcripts n in which a change was reported at least once; only learning strategies with $n > 1$ are displayed.

Changes regarding the use of resource management strategies reported by students in retrospect were also examined. As can be seen from Figure 15, for exam preparation, changes in effort were reported most frequently. For working mathematics problems, the change reported most often was an increased use of social strategies.

4.4.3.2. Use of learning offers

For relevant learning offers, categories had been defined a priori which covered a) the purposes for which students used them, the way in which they used them and reasons for not using them, b) the frequency with which students used them and c) students' evaluation of the learning offers. Inductive generation of subcategories led to the identification of further learning offers not identified in advance. Furthermore, category type a) was split up into separate subcategories, which were each subdivided into further subcategories.

Table 15 displays the reasons why students used various learning offers. Detailed results for all subcategories can be found in Table 25 in appendix 7.6. Every learning offer was used for exam preparation and a high number of learning offers was used to work on mathematics problems. However, students also made selective use of learning offers for specific purposes. For example, lectures were the only learning offer for which the instructor was cited by several students as an important reason for use. Other special reasons for use included having a good conscience or a feeling or safety when attending the lecture, being introduced to important topics, contents and methods and seeing examples, which students believed to benefit their understanding. Lecture slides and lecture recordings were the only learning offers for which reviewing lectures or making up for missed lectures were important purposes or reasons to use them. In addition, a specific reason to use lecture recordings was enriching lecture slides, for example in case of problems understanding them. A unique reason to use (i.e. work) mathematics problems was the bonus for the exam received for successful completion of a certain proportion of problems during the semester.

Table 15

Reasons for using learning offers

Category	*n*	%
Lecture	18	66.67
Exam preparation	7	25.93
Examples	6	22.22
Feeling of safety / good conscience	3	11.11
Instructor	5	18.52
Introduction to topics / methods / contents	8	29.63
Other	5	18.52
Working mathematics problems	5	18.52
Lecture notes	10	37.04
Dealing with contents	4	14.81
Exam preparation	4	14.81
Working mathematics problems	8	29.63
Lecture recordings	15	55.56
Comprehension (problems)	3	11.11
Exam preparation	5	18.52
Replacement / review of lecture	5	18.52
Supplementing lecture slides	7	25.93
Working mathematics problems	6	22.22
Lecture slides	24	88.89
Comprehension / content	3	11.11
Exam preparation	11	40.74
Replacement / review of lecture	6	22.22
Working mathematics problems	20	74.07
Mathematics problems	27	100.00
Comprehension / learning	11	40.74
Exam bonus	15	55.56
Exam preparation	27	100.00
Other	2	7.41

Office hour	18	66.67
Exam preparation	8	29.63
Learning mathematics / comprehension	7	25.93
Working mathematics problems	16	59.26
Old exams & exam preparation problems	25	92.59
Exam preparation	25	92.59
Other e-learning offers	12	44.44
Exam preparation	12	44.44
Other face-to-face offers	13	48.15
Exam preparation	9	33.33
Learning mathematics / comprehension	3	11.11
Working mathematics problems	6	22.22
Sample solutions	15	55.56
Exam preparation	5	18.52
Working mathematics problems	13	48.15
Tutorial	26	96.30
Applying theory	2	7.41
Exam preparation	4	14.81
Learning mathematics / comprehension	9	33.33
Other	2	7.41
Submitting and collecting mathematics problems	2	7.41
Working mathematics problems	25	92.59
Video tutorials	21	77.78
Exam preparation	12	44.44
Introduction to problem solving methods	10	37.04
Other	2	7.41
Working mathematics problems	6	22.22

Note. Reported are only categories with $n > 1$; n = number of transcripts in which a category was reported at least once; % = percentage of overall transcripts in which a category was reported at least once.

Table 16

Ways of using learning offers

Category	*n*	%
Lecture	13	48.15
Asking questions	3	11.11
Listening only	3	11.11
Paying attention selectively	3	11.11
Preparation / review	5	18.52
Taking notes	4	14.81
Lecture recordings	5	18.52
Keeping in readiness	2	7.41
Selective use	2	7.41
Taking notes	2	7.41
Lecture slides	10	37.04
Creating a summary	6	22.22
During the tutorial	8	29.63
Mathematics problems	21	77.78
Peers	13	48.15
Working alone	16	59.26
Office hour	8	29.63
Asking specific questions	8	29.63
Old exams & exam preparation problems	8	29.63
Peers	7	25.93
Solving under time pressure	2	7.41
Tutorial	17	62.96
Asking specific questions	6	22.22
Collaboration with peers	8	29.63
Several peer week	8	29.63

Note. Reported are only categories with $n > 1$; n = number of transcripts in which a category was reported at least once; % = percentage of overall transcripts in which a category was reported at least once.

Only for some learning offers did ways in which students used them surface (see Table 16). For example, students reported solving mathematics problems on their own or together with peers. Learning offers involving contact with instructors were used to ask specific questions. And lecture (recordings) were used selectively, e.g. by reducing or heightening attention, respectively by rewinding or forwarding. A more detailed table including all subcategories can be found in appendix 7.6 (Table 26).

As can be seen from Table 17, common reason for not using learning offers were lacking need and a preference for other learning offers. In addition, specific reasons for non-use emerged for specific learning offers. For example, concerning the lecture, students cited conflicting academic obligations, problems with paying attention and understanding and a preference for studying the contents on their own. A lacking relevance with respect to the exam was cited by students as a reason why they did not work mathematics problems and also for non-visiting the lecture (e.g., due to a focus on proofs). And a unique reason provided by students for not using old exams or exam preparation problems was that no solutions were available for them. A detailed table including all subcategories can be found in appendix 7.6 (Table 27).

Table 17

Reasons for non-use of learning offers

Category	***n***	%
Lecture	16	59.26
Comprehension / attention difficulties	6	22.22
Date / frame conditions	3	11.11
Lacking relevance for exam	5	18.52
Not useful / sensible	3	11.11
Other	3	11.11
Other academic obligations	2	7.41
Preference for dealing with contents on one's own	5	18.52
Preference for other learning offers	9	33.33
Lecture notes	4	14.81
Preference for other learning offers	4	14.81
Lecture recordings	14	51.85
Lacking need	10	37.04
Other	2	7.41
Preference for other learning offers	6	22.22
Mathematics problems	6	22.22

Lacking capacity / time	3	11.11
Lacking relevance for exam	3	11.11
Office hour	9	33.33
Lacking need	2	7.41
Lacking time	3	11.11
Not useful / sensible	4	14.81
Preference for other learning offers	3	11.11
Old exams & exam preparation problems	6	22.22
Lacking solution	2	7.41
Overlap with other learning offers	2	7.41
Preference for other learning offers	2	7.41
Other e-learning offers	2	7.41
Not useful / sensible	2	7.41
Other face-to-face offers	4	14.81
Date / frame conditions	2	7.41
Other	2	7.41
Tutorial	5	18.52
Date / frame conditions	3	11.11
Other	2	7.41
Video tutorials	11	40.74
Lacking need	8	29.63
Not known	2	7.41
Other	2	7.41

Note. Reported are only categories with $n > 1$; n = number of transcripts in which a category was reported at least once; % = percentage of overall transcripts in which a category was reported at least once.

Figure 16 shows the frequency with which students used learning offers. As can be seen, tutorials were the learning offer used most intensively. In fact, over 85% of the sample reported using them very often. Another offer used intensively were lecture slides (used very often by 52% of the whole sample and 93% of those students, for whom frequency of use could be rated). Great variance in frequency of use indicated by similar numbers of students reporting very high and very low use were found for lectures and office hours. Particularly low rates of use, both with respect to absolute numbers as well as relatively to the overall number of students for whom a rating could be made were found for lecture recordings.

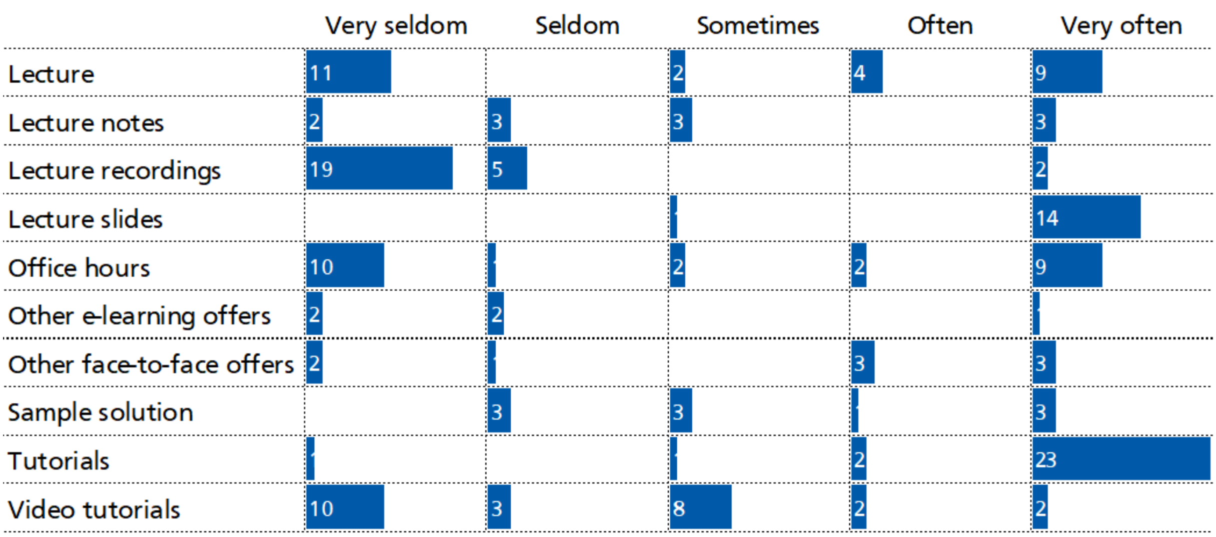

Figure 16. Frequency of use of learning offers. Ratings were made by two coders based on participants reports. Displayed are the number of transcripts *n*, only for learning offers with *n* > 1.

In Figure 17, students' evaluations of learning offers, or more specifically, the helpfulness of the learning offers as perceived by students, are depicted. Students appreciated nearly all learning offers. Particularly tutorials were judged as very helpful by the majority of the sample. For lectures, again a very diverse picture emerged with approximately equal numbers of students rating them to be very helpful and not helpful. And for lecture recordings and sample solutions, perceived helpfulness as judged by students was relatively low.

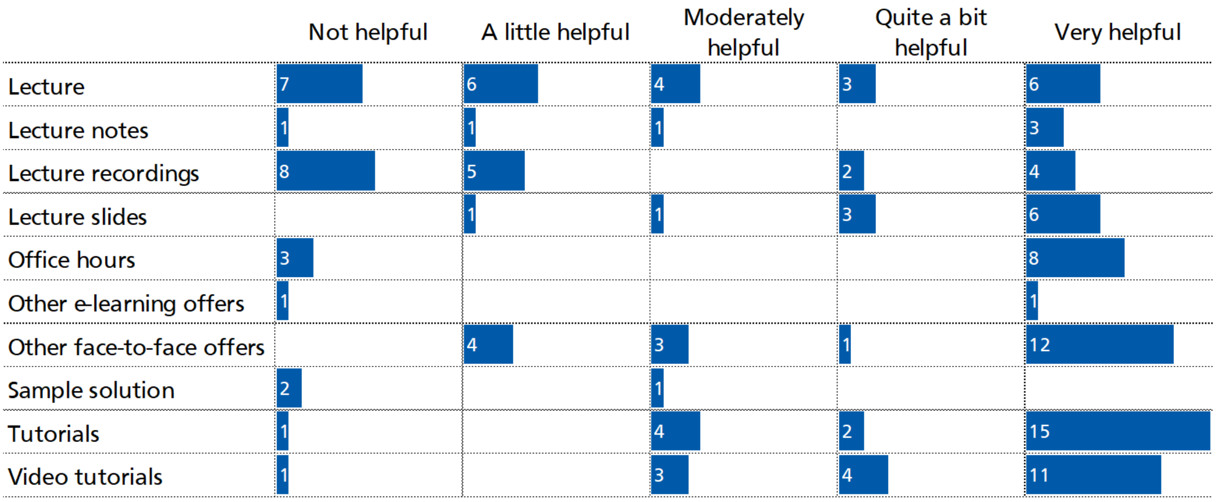

Figure 17. Perceived helpfulness of learning offers. Ratings were made by two coders based on participants reports. Displayed are the number of transcripts *n*, only for learning offers with *n* > 1.

Lastly, it was also investigated whether students' use and evaluation of learning offers had changed over the course of their studies, based on their retrospective accounts. Four students reported that their use of a learning offer had not changed, 22 had experienced a change and for one student, no data was available. As can be seen from Figure 18, the learning offer for which the most changes were reported was the lecture, followed by office hours, other face-to-face offers, and tutorials. The most common change with respect to the lecture was a reduced frequency of visiting the lecture, whereas for office hours the most common change was a heightened frequency of use, and for other face-to-face offers, availability had changed (i.e. it had been reduced). Overall, most reported changes referred to frequency of use, with more comments indicating a decrease than an increase of use. In addition to the results presented in Figure 18, two students reported that their evaluation of the tutorials was variable over the semesters, depending on the tutor, but did not indicate a clear tendency. Furthermore, some students also reported changes over the course of one semester. Two students each reported an increased or decreased use of office hours, and five students each reported an increased use of video tutorials, and a decreased use of lectures.

			Frequency of use		Evaluation	
	Availability	Use	Decrease	Increase	Deterioriation	Improvement
Lecture		4	10	2		3
Lecture notes		2	2			
Lecture recordings			3			
Lecture slides				2		
Mathematics problems			4	2		2
Office hours			3	9		2
Other face-to-face offers	10		5			
Tutorials	2			3	2	3
Video tutorials	3					

Figure 18. Reported changes with respect to learning offers over the course of studies. Displayed are the number of transcripts *n* in which a change was reported at least once; only learning offers with $n > 1$ are displayed.

4.4.3.3. Time spent studying

With respect to the time spent studying, students were asked how much time they spent studying during the semester and during the semester break (e.g. when preparing specifically for the exam). The results showed that five students spent between 4 and 6 hours, 14 students spent between 7 and 9 hours and six students spent 10 or more hours per week studying for mathematics. This included also time spent in learning offers. For two students, no information was available.

With respect to the time spent studying during semester break, students measured time in different categories, yielding more differentiated results. The majority of students ($n = 19$) spent at least one week or seven days during semester break preparing specifically for the exam. Of those, 10 students reported spending at least two weeks or 14 days, whereas nine students reported spending more than one but less than two weeks (or between seven and 13 days). Three students reported spending less than one week or seven days preparing intensively for the exam. For five students, no information was available concerning the overall time they spent studying during semester break. Moreover, many students provided more specific information concerning their studying habits. Seven students mentioned that they studied every day during their exam preparation phase. Furthermore, 14 students detailed the number of hours they spent studying per day during the exam preparation phase. Of those, four studied for not more than 5 hours, four for 6 to 8 hours and six for more than 8 hours.

4.5. Discussion

The current study aimed at exploring several (meta-)cognitive, motivational and behavioral aspects of engineering students' self-regulated learning in tertiary mathematics education. Anonymized transcripts from semi-structured interviews conducted with engineering students enrolled in a mathematics course at a university of technology in Germany were analyzed using a deductive-inductive method. In the following, results with respect to the individual research questions will be discussed, followed by an outline of implications for research and practice, a description of limitations of the study and some concluding comments.

4.5.1. (Meta-)Cognition

Research question 1 focussed on (meta-)cognitive learning strategies which engineering students used a) for working mathematics problems and b) exam preparation. In line with the expectations declared in advance, the majority of students reported using elaboration strategies for working mathematics problems. In particular, students used examples, for instance in case of difficulties, to increase understanding but also to replicate or adapt the procedure shown. These results confirm and extend findings from previous studies which showed that in tertiary mathematics education, students use examples in case of difficulties (Rønning, 2017) or to mimic the procedure (Lithner, 2003). Furthermore, also confirming a priori expectations and previous literature (Griese, 2016; Kortemeyer & Biehler, 2012), metacognitive strategies were commonly used when working mathematics problems. For example, in line with previous findings not specific to engineering students (Ní Shé et al., 2017), several students used sample solutions to correct their own work. Other sources used for control were peers and office hours. Furthermore, planning strategies were reported by nearly half of the sample and thus, were the most frequently reported type of metacognitive strategy. This result stands in contrast to previous findings that reaction strategies tend to be used more often by engineering students in mathematics courses compared to planning and control strategies (Griese, 2016).

With respect to exam preparation, the present study showed that rehearsal strategies and specifically, rehearsing by working mathematics problems (both ones which had been worked before and new ones) was a strategy adopted by all students. Furthermore, organizational strategies (e.g. creating summaries such as a formulary) and metacognitive strategies were also reported by the majority of the sample. Thus, the study confirms and extends previous research on engineering students' learning strategies for exam preparation (Anastasakis et al., 2017). However, in contrast to the results by Griese (2016), also for exam preparation, planning strategies were more often reported than controlling and reacting strategies. Especially planning of the scope and content of learning, assessment of comprehension and learning and deciding whether to adapt or keep up learning strategies and behavior were important specific metacognitive learning strategies reported by students. Furthermore, the high frequency of use of rehearsal strategies, and especially the repeated working of the same mathematics problems, align well with the claims made by Kürten et al. (2014) that memorizing procedures is an important learning strategy of STEM students in mathematics courses.

Another aspect deserving attention concerns the strategy of critical checks that is included in the questionnaire by Wild and Schiefele (1994), which served as a basis for the development of the coding frame in the current study. In the current study, critical checks did not emerge as a strategy, neither with respect to exam preparation nor with respect to mathematics problems. This aligns well with the assumptions of Griese, Glasmachers, Härterich, et al. (2011) that this strategy is not appropriate for mathematics tertiary education.

With respect to the development of (meta-)cognitive learning strategies (i.e. research question 2), the results cannot be directly compared to previous studies involving engineering students, since these only tracked development over the course of one semester (Griese, 2016; Griese, Glasmachers, Härterich, et al., 2011). The current study thus extends respective knowledge and demonstrated in particular a tendency for an increased use of metacognitive learning strategies. For organizational strategies, Kolter, Liebendoerfer and Schukajlow (2016) found a slight decrease over the first two semesters in a sample of prospective teachers, whereas they identified a slight increase of rehearsal strategies. These results could only partly be confirmed in the current study, as for organizational and rehearsal strategies, both increases as well as decreases were reported by students with similar frequency. However, it needs to be kept in mind that the changes were reported retrospectively by students and thus reflect only those changes that students were aware of, respectively which they perceived to have occurred during their studies at the time of the interviews.

4.5.2. Motivation

4.5.2.1. Achievement goals

Research question 3 focussed on students' achievement goals. No specific categories were defined a priori due to the great variety of theories and models. Instead, goals were defined inductively based on the reports of the students and are therefore unique to the current study. However, in line with the findings of Anastasakis et al. (2017) and thus, the expectations defined in advance, passing the course, achieving a good grade, acquiring knowledge and understanding of contents or scientific thinking skills and acquiring knowledge, understanding or skills in order to be able to apply them during one's studies emerged as important goals. However, in contrast to results by Anastasakis et al. (2017) achieving a good mark was a common goal but not the most common goal, which was passing the course.

When comparing the goals found in the current study to prominent achievement goal theories, several similarities or overlaps can be identified. Most obvious is the similarity of the knowledge-related goals found in the current study to learning goals as defined by Grant and Dweck (2003) and mastery-approach goals as defined by Elliot and colleagues (Elliot & Church, 1997). These goals are characterized by a desire to increase knowledge, skills and understanding. However, differing from these goals, the aspect of challenge was not part of knowledge-related goals found in the current study. For exam-related goals, inspection of subcategories (i.e. specific goals) shows further overlap with existing theoretical models.

Clearly, the goal of achieving better results than other students is comparable to performance-approach goals (Elliot & Church, 1997), respectively normative goals (Grant & Dweck, 2003). However, students did not explicitly mention appearance concerns. This aligns with the findings by Kaldo and Reiska (2012), who reported that in first-year mathematics courses, students from various degree programs rated mastery goals higher than performance-approach goals with a focus on appearance concerns. The goal of achieving good grades maps well onto the construct of outcome goals as described by Grant and Dweck (2003).

To the authors knowledge, the other two goals, i.e. achieving a mediocre grade and passing the course, have not been explicitly included in the models of Grant and Dweck (2003) and Elliot and Church (1997). However, based on their description and work of other researchers, some links can be suggested. Passing the course can be understood as the desire to avoid failure, which is defined using absolute standards. Following this logic, this goal can be understood as a mastery-avoidance goal. A comparable argumentation can also be found in Ryan, Ryan, Arbuthnot, and Samuels (2007). Taking these assumptions to be true, mastery-avoidance goals had a high prevalence in the current study, a finding that stands in contrast with previous studies (Elliot & McGregor, 2001; Elliot & Murayama, 2008). Alternatively, one could hypothesize that the goal to pass the course might also be connected to the desire of not losing face in front of others, such as one's peers or family. In this case, the goal would be more closely aligned with performance-avoidance goals as described by Elliot and Church (1997). However, an inspection of relevant codings showed that students did not mention any appearance concerns in relation to the goal of passing the course. Thus, the interpretation as a performance-avoidance goal was not be supported by the data.

The goal to achieve a mediocre grade is similar to that of being average, which has been characterized by other researchers as both a performance-approach and performance-avoidance goal (Urdan & Mestas, 2006). In the current study, students' focus was more on avoiding worse results, which suggests a greater similarity to performance-avoidance goals as defined by Elliot and colleagues (Elliot & Church, 1997). Similarly, at first sight, application-related goals cannot be directly mapped onto the models of Elliot and colleagues (Elliot & Church, 1997) and Grant and Dweck (2003). However, one could argue that application-related goals are actually mastery-approach goals, as they involve striving for acquistion of skills, knowledge and understanding. What differentiates them from knowledge-related goals is the reason for pursuing this goal, which is the application of knowledge, understanding or skills, e.g. during one's studies or future employment. Potentially, such reasons for pursuing aims need to be considered separately from the aims themselves (see for example Urdan and Mestas (2006) for a similar approach). Furthermore, the descriptions of students bear resemblance to the construct of task value described by Pintrich et al. (1991) or the construct of endogenous perceptions of instrumentality (Husman & Hilpert, 2007), both of which have been found to be related to achievement goals. For example, Pintrich (2000a) showed that students reporting both high mastery and performance-approach goals reported the highest level of task value with respect to mathematics and showed the smallest decline in task value from the beginning of eigth grade to the end of ninth grade. And in an online developmental mathematics course, Husman and Hilpert (2007) found positive and significant correlations between students' endogenous perceptions of instrumentality and mastery goals (and to a lesser extent also with performance-approach and performance-avoid goals). Lastly, the current study showed that most students adopted more than one goal and showed very individual goal combinations. This finding also is in line with the assumptions made in advance and previous research in the domain of mathematics tertiary education (Cano & Berbén, 2009) and strengthens claims of other researchers that students pursue multiple goals in parallel (Harackiewicz, Barron, Tauer, & Elliot, 2002; Pintrich, 2000a, 2000b, 2003).

When interpreting the results concerning the development of achievement goals over students' course of study (i.e. research question 4), as noted above, it needs to be kept in mind that the identified changes were based on students' retrospective accounts. As expected, at least some students reported changes concerning their achievement goals. However, in contrast to previous findings from mathematics tertiary education (Schreiber et al., 2011), no change concerning performance-avoidance goals was detected. Instead, in line with Fryer and Elliot (2007) who found that students enrolled in introductory psychology courses showed both increases and decreases of mastery-avoidance goals over time, in the current study, both changes from aiming to pass the course to striving to achieve a good grade as well as in the reverse direction were reported by students. Furthermore, a change reported relatively often was one from from aiming to pass the course to (also) pursuing application-related goals.

4.5.2.2. Attributions

Research question 5 focussed on students' attributions for their exam results. The results showed that factors perceived by students as influencing exam results were ability, knowledge or comprehension, available time for learning, effort, exam behavior, exam construction, instructors, learning behavior, learning offers, luck, motivation, nervousness and peers. More specific factors cited commonly were rehearsing respectively working mathematics problems, investment of time, tutorials, additional face-to-face offers, identifying or focusing on exam-relevant topics, tutors and the professor (especially his or her teaching methods). In addition, many more specific causes were identified, such as availability of learning offers and mistakes made in the exam.

Thus, the results confirm the expectations defined in advance and support and extend previous studies in which effort (Anthony, 2000; Maidinsah et al., 2014; Pyzdrowski et al., 2013; Schutz et al., 1998), teaching quality including instructors' communication skills, motivation, homework completion and help and support (Anthony, 2000; Pyzdrowski et al., 2013) were identified as important attributions. In line with previous studies (Anthony, 2000; Maidinsah et al., 2014), effort was one of the most often cited causes. This result held true also when only spontaneous answers of students were analyzed. For two other aspects however, this analysis yielded very different results. When asked directly whether learning offers and instructors had influenced their exam results, the great majority of students confirmed this. However, only a minority reported these factors spontaneously. Thus, the current study parallels previous findings showing effects of measurement type (Whitley & Frieze, 1985). In addition, previous studies showed that students tend to attribute their success (more) to internal factors and failure (more) to lack of effort and external factors (Anthony, 2000; Cortés Suárez, 2004). These results (and the expectations defined thereupon) could partly be confirmed in the current study. The most often cited factors for success except from instructors and learning offers (which were often triggered by the interviewer) were indeed internal factors, namely effort, learning behavior and motivation. For failure, consistent with previous literature, lack of effort was the cause cited most often, followed by exam construction. Lastly, it is also interesting to compare the results to those of Griese and Kallweit (2016). The authors report that lecturers rated the importance of homework for study success highest, followed by effort and intelligence or ability. Similarly, students in the current study commonly mentioned working mathematics problems as a relevant factor for exam success (although differing from Griese and Kallweit (2016) this was subsumed under effort).

4.5.3. **Behavior**

4.5.3.1. Resource management strategies

Research question 6 referred to important resource management strategies for a) working mathematics problems and b) exam preparation. In line with previous studies (Anastasakis et al., 2017; Griese, 2016) and expectations, social learning strategies in general and peers or friends in particular played an important role both when working on mathematics problems and when preparing for exams. Furthermore, with respect to mathematics problems, the results strengthened previous findings not specific for engineering students, as students reported copying solutions from friends and peers (Ableitinger, 2012; Liebendörfer & Göller, 2016; Liebendörfer & Hochmuth, 2012; Rach & Heinze, 2013) and using sample solutions (Ní Shé et al., 2017). Also in line with previous research and the expectations developed thereupon, effort regulation (Griese, 2016; Kortemeyer & Biehler, 2012) and use of literature (Anastasakis et al., 2017; Griese, 2016; Rønning, 2017) emerged as important strategies for both exam preparation and working mathematics problems. In particular, confirming and extending the findings by Anastasakis et al. (2017), lecture slides were an important source for both situations and prior exams were commonly used to rehearse for the exam. However, in contrast to previous results (Anastasakis et al., 2017; Rønning, 2017), use of (text-)books was only reported by a minority of students for both situations. This might be due to the broad range of other offers available to students online, including lecture slides, lecture notes and lecture recordings. Furthermore, management of the study environment emerged as a commonly used strategy only for working mathematics problems, thus, confirming previous studies with engineering students in mathematics education (Griese, 2016) only in part.

Concerning the development of the use of resource management strategies (i.e. research question 7) over time, to the author's knowledge, this study is the first to present evidence for more than one semester. Especially important seems the finding, that both for exam preparation and working mathematics problems, an increase in social learning strategies was a) more commonly reported than a decrease, and b) belonged to the most often reported changes overall. A clear tendency for an increased use over students' course of studies was also observed for time management, whereas for use of literature, an ambiguous picture emerged, as only decreases were reported with respect to exam preparation but only increases with respect to working mathematics problems. For effort, decreases and increases were reported with similar frequency for both situations. Thus, these results extend previous findings by Griese (2016) who found a decrease of the use of literature, effort management and attention problems over the course of one semester in a sample of engineering students enrolled in first-year mathematics courses. Yet, again, it needs to be pointed out that only those changes could be identified that students were aware of and reported at the time of the interview, looking retrospectively at their previous studies.

4.5.3.2. Use of learning offers

Research question 8 focussed on students' use and evaluation of learning offers. Based on frequency of use, tutorials and lecture slides and to a lesser extent also lectures, office hours and other face-to-face offers emerged as important learning offers. Based on their perceived helpfulness, tutorials and office hours and to a lesser extent also other face-to-face offers, video tutorials and lecture slides could be identified as important learning offers. Hence, the results confirmed the expected importance of tutorials and video tutorials and previous research demonstrating the appreciation of tutorials (Harris & Pampaka, 2016; Roegner & Heimann, 2014) and video tutorials (Anastasakis et al., 2017; Loch et al., 2012) by engineering students in mathematics tertiary education. For homework, existing data did not allow to rate frequency of use or evaluation. The respective expectation could thus neither be confirmed nor discarded.

As suggested by a previous study in the field of statistics education (Rodgers, 2001), tutorials were used more intensively than lectures. Furthermore, in line with findings from previous studies (Harris & Pampaka, 2016; Roegner & Heimann, 2014) and the expectations for the current study grounded therein, working mathematics problems and asking respective questions were identified as important reasons to attend tutorials. In addition, several reasons not identified in previous research could be found for tutorial attendance, including learning and achieving understanding and preparing for exams. The only specific reason not to use tutorials cited by several students were issues of timing or frame conditions. Similar reasons have also been reported for other disciplines (Kottasz, 2005). Concerning the way in which students used tutorials, the present study showed that students asked specific questions prepared in advance. Thus, it supports and extends findings by Harris and Pampaka (2016) who reported that the opportunity to ask questions in tutorials was especially appreciated by students.

With respect to lectures, ambiguous results with respect to frequency of use and evaluation were expected. This expectation was confirmed. In line with previous findings (Roegner et al., 2016) a non-trivial proportion of students visited lectures very seldom, however, in line with other previous studies (Rønning, 2014, 2017) there was also a subgroup of students who visited the lecture very often. The diversity among students was also reflected in other findings: Lectures were the resource for which the most diverse reasons for use and non-use were provided by students. In agreement with a previous study conducted in mathematics tertiary education for engineering students (Rønning, 2017) and the expectations expressed in advance, a feeling of safety or good conscience and an introduction to topics, methods and contents were identified as reasons for visiting the lecture. Furthermore, some students specifically mentioned that they asked questions in (respectively during breaks or after) the lecture, which also aligns well with previous research (Rønning, 2017) and the a priori set expectations. However, contrary to the expectations and previous research (Rønning, 2017), being incentivized to structure one's learning through the lecture could not be identified as a reason for attendance. Instead, in line with research from other disciplines, the lecturer (Gysbers, Johnston, Hancock, & Denyer, 2011; Kottasz, 2005) was identified as a further reason for attending. Also in line with previous research and a priori expectations, problems understanding or following the lecture and a preference for other learning offers including those offered by student tutors as well a lacking relevance for the exams due to the focus on proofs (Harris & Pampaka, 2016; Roegner et al., 2016) were reasons students gave for not attending the lecture. Other reasons found mirrored those reported by studies conducted in other disciplines: conflicting academic obligations (Davis, Hodgson, & Macaulay, 2012; Gysbers et al., 2011; Kottasz, 2005), no perceived benefit (Kottasz, 2005), and unsuitable time or frame conditions (Davis et al., 2012; Gysbers et al., 2011; Kottasz, 2005). However, in contrast to research from other disciplines, external factors such as emergencies and bereavement (Kinlaw, Dunlap, & D'Angelo, 2012), sickness (Kinlaw et al., 2012; Kottasz, 2005; Massingham & Herrington, 2006), problems with transportation (Gysbers et al., 2011; Kottasz, 2005) and work (Gysbers et al., 2011; Kottasz, 2005; Massingham & Herrington, 2006) were not mentioned by students as reasons for not attending lectures. Instead, an additional reason not to use lectures identified in the current study was to the author's knowledge unique: a preference to deal with the learning content on one's own.

Concerning lecture recordings, the study supports the results by Rønning (2014, 2017) who found rather low rates of use in mathematics courses for engineering students. Furthermore, in agreement with a previous study (Rønning, 2014) and the expectations for the current study, reviewing (or replacing) the lecture emerged as a reason to use lecture recordings. Further reasons found in the current study included exam preparation, a reason which has also been found in studies conducted in unspecific mathematics courses (Gunesch, 2013a, 2013b), respectively in studies from other disciplines (Tillmann, Bremer, & Krömker, 2012). A discussion of the results concerning video tutorials can be found in Wehner (2018).

In addition, the current study showed that students used a variety of other learning offers, including office hours of student tutors. Since to the author's knowledge, this study is the first to investigate the use of these offers (at least among engineering students in mathematics courses), the findings are especially valuable and enrich respective knowledge. Similarly, the present study was the first to describe students' reasons for completing homework in mathematics courses (i.e. for working mathematics problems). These included learning and understanding, preparation for exams but also the bonus for the exam received for correctly solving a certain amount of problems.

Research question 9 dealt with the development of students' use and evaluation of learning resources over the course of study. Again, to the author's knowledge, the present study was the first to examine this for mathematics tertiary education for engineering students and again, the informative value of results is somewhat limited due to the retrospective assessment used. The results showed a decline in attendance in lectures over the course of a specific semester, a finding well aligned with a study conducted in a statistics course (Rodgers, 2001). However, in contrast to the latter study and the expectation framed in advance, for tutorials, no tendency for a decline within semesters could be identified. In addition, the present study could not confirm an increased use of lecture recordings in advance of tests and examinations, which had been found in several studies conducted in other domains (Copley, 2007; Rust & Krüger, 2011; von Konsky et al., 2009). The lack of findings might be due to the small sample size and the low number of students using lecture recordings at all, as well as due to the methodology (since students were not necessarily asked about the development of their use of lecture recordings). For video tutorials however, an increased use within semesters was reported by 19% of the sample. This finding is in line with previous research and the a priori expectations (Kay & Kletskin, 2012). For homework (i.e. mathematics problems), the most commonly reported change was a reduced frequency of use over the course of study. Since to the author's knowledge, no study has yet explored similar changes, this finding can only be considered as a starting point for further research.

4.5.3.3. Time spent studying

Based on previous research (Jaworski, 2008), it was expected that students would spend up to six hours per week studying for mathematics courses (i.e. research question 10). However, the results showed that the majority of students spent more than six hours per week studying for mathematics and a non-trivial amount of time preparing intensively for the exam during semester break. Thus, although results are very difficult to compare to existing studies due to different operationalizations of time spent studying, the amount of time spent studying is potentially higher than that reported from other countries both specifically for mathematics education for engineering students (Jaworski, 2008) as well as for mathematics education in general (Anthony, 2000), but more similar to that reported in a study conducted in Germany in a mathematics course for business sciences (Laging & Voßkamp, 2016).

4.5.4. Implications for research

The present study strongly supports the benefits of a domain-, course- or even task-specific assessment of learning strategies, advocated also by other researchers (Eley & Meyer, 2004). It showed that students made differential use of strategies for different tasks within a mathematics course and although the general learning strategies described by Wild and Schiefele (1994) could successfully be used as a basis for the deductive development of main categories, the specific learning strategies described by students were often specific to the domain of mathematics, respectively mathematics-intensive courses. For example, the creation of a formulary emerged as a mathematics-specific organizational strategy for exam preparation. Furthermore, the current study yielded initial evidence for several interesting changes of learning strategies for exam preparation and working mathematics courses over the course of several semesters. Longitudinal studies are called for to investigate these changes more thoroughly.

Furthermore, as described above, despite the inductive approach to data analysis taken in the current study, several goals emerged which map directly onto constructs as defined by well-established theories (in particular mastery-approach, respectively learning goals, performance-approach goals or normative goals and outcome goals). In addition, further goals could be argumentatively linked with mastery-avoidance and performance-avoidance goals. Thus, the present study confirms these models (Elliot & Church, 1997; Grant & Dweck, 2003) at least partly. However, similar to a qualitative study conducted in the school context (Lee & Bong, 2016), no model could be confirmed completely. The aspect of appearance inherent in performance-approach, performance-avoidance and ability goals did not emerge at all in students' descriptions, neither did the aspect of challenge in mastery-approach respectively learning goals. As a matter of fact, in the past, researchers have discussed intensively whether or not performance goals should include both normative and appearance aspects or only one of them, leading amongst others to the separation of ability and normative goals in the model by Grant and Dweck (2003). The current study strengthens calls for a clear separation of these aspects and potentially for the elimination of appearance aspects. Future qualitative studies could contribute to solving this dispute, as they allow to examine students' goals based on their own descriptions and thus, to avoid influencing students through the wordings of instruments. Nonetheless, it would also be interesting to explicitly ask students about appearance concerns in addition to their spontaneous description of goals.

Furthermore, the current study clearly makes a case for investigating goal profiles. Future studies should continue the exploration of students' goal profiles using bigger samples in order to identify and describe common goal profiles with more certainty.

The author further believes that the current study should motivate researchers to take qualitative approaches to studying attributions. Although Weiner, the probably most prominent researcher in the field of attribution research, noted that people make attributions for achievement to a variety of causes (see for example Weiner (1979)), in many existing studies, attributions were narrowed down to the quartet of ability, effort, luck and task difficulty (e.g. McMahan, 1973). As demonstrated impressively in the current study, this is a severe restriction and limits the informative value of the respective results. Semi-structured interviews such as the ones conducted in the current study allow participants to describe the full range of causes to which they ascribe events in their own words. This gives greater weight to the causes found, especially those mentioned frequently and potentially leads to different (interpretations of) results. Furthermore, as has been done in the current study, interviews allow researchers to examine two related aspects or constructs: spontaneously mentioned causes and those factors students ascribe influence to when triggered. Both approaches provided interesting and valuable results not only for researchers but also for practitioners (see section 4.5.5).

In addition, the current study demonstrates that students show a complex pattern of use of different learning offers, including such not explicitly considered in advance. This should motivate researchers to focus not only on students' use of one specific learning offer, but rather to take into account all learning offers available to students (for an example, see Laging and Voßkamp (2016)). Furthermore, it questions the importance of external factors such as sickness, work, or problems with transportation, which have been reported as reasons for non-attendance of lectures and tutorials in other disciplines (Gysbers et al., 2011; Kinlaw et al., 2012; Kottasz, 2005; Massingham & Herrington, 2006). Studies in which these factors were identified often asked students to rate the importance of a pre-set list of factors for non-attendance. In contrast, students in the current study were asked to explain spontaneously, why they did not attend. One explanation for the contradicting findings might be that external factor are reasons why students do not attend singular sessions of a lecture or tutorial, whereas the reasons identified in the current study (e.g. a preference for other learning offers) are reasons why students choose not to use a learning offer at all. Another possibility might be that the reasons found in the current study apply only to the domain of mathematics education, whereas those found in other disciplines are not relevant here. Future studies are needed to explore potential effects of method or discipline further.

Results concerning the time spent studying underlined the importance of deciding in advance of a study, how time spent studying is defined and to which period of time it refers. For example, in the current study, differences concerning time spent studying emerged between the semester and semester break, with the first being characterized for many students by regular use of different learning offers, whereas the majority of students reported an intensive but rather short time span of preparing for exams during semester break. Up to now, existing studies vary greatly in their definition and measure of time spent studying (e.g. Anthony, 2000; Jaworski, 2008; Laging & Voßkamp, 2016). This limits the comparability of the results and prevents to come to clear conclusions. Future research should address this problem.

4.5.5. Implications for practice

The results of the current study are useful for university administrators, instructors and students. For example, they demonstrate that students have manifold learning strategies with respect to mathematics and that some of them actually control the effectiveness of these strategies and adapt them accordingly. Previous research has demonstrated the success of content-independent trainings (e.g. Bellhäuser et al., 2016; Dörrenbächer & Perels, 2016; Schmitz, 2001) and courses (e.g. Hoops, Yu, Burridge, & Wolters, 2015) in increasing students perceived self-regulated learning. The results from the current study however suggest, that university administrators or instructors might benefit from also considering subject-specific strategies when developing courses supposed to teach self-regulated learning strategies. For example, it might be useful to involve students in higher semesters in the construction of the curriculum or even the teaching process itself.

The diversity of goal profiles identified in the current study should serve as a reminder to instructors, that each student is unique, driven by different goals and thus potentially also motivated by different educational interventions. Nonetheless, the centrality of two specific goals, namely those of passing the course and acquiring knowledge, understanding and skills in order to apply them during one's studies could provide the basis for designing motivating learning offers and supporting students. For example, it can be hypothesized that students pursuing the goal of acquiring knowledge, understanding and skills for application in their future studies would appreciate and benefit from the demonstration of links between course contents and other areas of their studies. Emphasising such connections has been a part of recent attempts to improve mathematics tertiary education for engineers (Dahmen & Freyn, 2014; Dehling et al., 2014). Furthermore, assuming that passing the exam is not only a common goal, but also an important goal for the individual student, this goal could be used to motivate students to take advantage of the learning offers available. It also indicates the need to support students in fear of missing the goal, both functionally as well as psychologically.

Similarly, findings concerning the attributions students make about their exam results can serve as a basis to improve learning offers and to design interventions for improving academic achievement. Many of the factors identified as having a positive effect can also be understood as descriptions of factors that students perceive beneficial or helpful for learning, which should thus be maintained or even extended. For example, tutorials were mentioned by many students as having had a positive effect on their exam results, respectively as having been a cause of success. In a similar vein, factors identified as having a negative effect or being a cause of failure can help identify potential areas of improvement. Furthermore, comparing students' attributions with empirical results concerning factors, which objectively influence academic results might help identify factors which are underestimated by students. For example, it is relatively well established that class attendance is positively linked with academic achievement (Credé et al., 2010), also for mathematics courses (Cretchley, 2005; Schreiber, Fischer, Biehler, Hänze, & Hochmuth, 2012). However, in the current study, only few students mentioned lectures as a factor influencing their exam results. This suggests that students might underestimate the importance of attendance. Findings such as this could inspire changes in communication about and in learning offers. For example, lecturers could make students aware of such disparities by sharing the results of the studies with them.

Furthermore, when designing learning offers, university administrators and faculty should consider the purposes for and ways in which students use them. This is essential in order to provide students with learning offers well suited to their needs and thus, to ensure that the limited resources are spent wisely. For example, the results of the current study demonstrate the value students ascribe to learning offers led by student tutors. These offers should thus be provided continously or even enriched despite the necessary resources in terms of personnel, time and money (Kürten et al., 2014). Furthermore, the results suggest that even though many students do not use live lectures, for others, they serve important purposes, including motivational ones. Based on this finding, the author advocates for not completely replacing lectures with other (e-learning) offers.

Lastly, results concerning the time spent studying show that students spend a non-trivial amount of time studying for mathematics. This will also influence the amount of time they can spend for other courses. In a similar vein, some students mentioned explicitly, that they had had too little time to prepare for exams and that this negatively influenced their results. University administrators should confront the time estimated for courses with the actual time students spend for it to ensure that students can complete their studies in time. For example, in the current study, when summing up the time spent per week over one semester (with a typical duration of about 16 weeks), the majority of students would spend between 112 and 144 hours studying for mathematics during the semester. Considering that in the phase of exam preparation, students spend additional time studying, which would amount to more than 40 hours for the majority of students (assuming that students spend at least seven days studying for at least six hours), this leads to about 150 hours or more which students spend for the course over all. According to the ratio suggested by the European Credit Transfer and Accumulation system (Europäische Union, 2015), this would imply that at least six credit points should be distributed for completing the course.

4.5.6. Limitations

Several limitations of the study need to be noted, which are at least in part linked directly with the methodological approach taken. Firstly, the study used a self-selected convenience sample of students from a specific mathematics course at a specific university. Due to this, the results can not be generalized beyond the current sample. Also, the sample was relatively small, which prevents further statistical analyses, for example concerning differences between different situations. Furthermore, due to the small sample size, several observations need to be interpreted cautiously, for example those concerning goal profiles (as most goal profiles were unique to individual students). Conducting the semi-structured interviews and the intensive method of data-analysis involving several readings and analyses of the complete transcripts required much time and effort. Thus, enlarging the sample was not possible with the given resources. Furthermore, in qualitative research, statistical representativeness and generalizability based on it play a minor role (Leydens, Moskal, & Pavelich, 2004; Mayring, 2016; Merkens, 2008). Also, the reported problems are commonly observed weaknesses of higher education research (Spinath & Seifried, 2018), although this is certainly no excuse. For future studies, the use of a mixed-methods approach might be considered to combine the benefits of qualitative and quantitative research approaches, in particular being able to test hypotheses while still recognizing the specific characteristics of individual students (Döring & Bortz, 2016; Leydens et al., 2004).

Secondly, in the current study, only retrospective self-reports were analyzed. The accuracy of students' self-reports concerning self-regulated learning has been challenged by studies showing discrepancies between students' self-reports and trace data concerning learning strategies (e.g. Winne & Jamieson-Noel, 2002). The inclusion of other data sources, such as observations of behavior (e.g. counting attendance at lectures or tutorials), judgement of others (e.g. instructors) or analysis of think-aloud protocols recorded during students' working of a mathematics problem might thus be valuable enrichments to future studies exploring students' self-regulated learning in mathematics tertiary education. Furthermore, longitudinal studies are needed to assess more in detail the development of students' self-regulated learning both quantitatively as well as qualitatively.

Thirdly, the current study focused only on describing (meta-)cognitive, motivational, and behavioral aspects of students' self-regulated learning. Highly relevant, especially with regard to the overall aim to improve students' success in mathematics tertiary education, are certainly also the consequences of these and other aspects of self-regulated learning for students' academic achievement. As described in the last chapter (Chapter 3), previous research suggests that metacognitive (Bol et al., 2016; Hudesman et al., 2014; Loong, 2012; Muis, 2008; Villavicencio & Bernardo, 2016; Zimmerman et al., 2011), motivational (Cho & Heron, 2015; Hodges & Kim, 2010; Zimmerman et al., 2011), and behavioral (Bol et al., 2016; Husman & Hilpert, 2007) aspects of self-regulated learning are associated with mathematics achievement. Future studies should further explore these associations, also specifically for engineering students. Other variables for which an association with students' self-regulated learning should be explored in the context of mathematics tertiary education in general and for engineering students in particular include students' satisfaction, interest in mathematics, and persistence in their degree programs.

Fourthly, analyzing interviews is a process which is by definition more subject to subjective influences than quantitative methods of data analysis (Urdan & Mestas, 2006). Thus, the subjective perspective of the author (e.g. previous knowledge, attitudes etc.) might have influenced data analysis. However, in qualitative approaches, this subjectivity is seen not as weakness but as an inherent characteristic and important element of research (Mayring, 2016). Nonetheless, several steps were taken to limit subjectivity to an acceptable degree. Firstly, steps of data analysis were defined in advance. Secondly, where deemed necessary, a second coder was used for coding and thirdly, where appropriate, theoretical approaches served as basis for category construction.

Fifthly, a threat with regards to interviews is students giving socially desirable responses (Bowling, 2005; Urdan & Mestas, 2006). However, in the author's opinion, the design of the study as well as its results do not suggest that such a phenomenon occurred. All interviews were conducted by the author of this dissertation, who was not involved in the teaching of the mathematics courses that the students recounted about, or any mathematics course for that matter. Furthermore, at the beginning of the interviews, students were informed about the measures to ensure privacy protection, including the anonymization of the transcripts (see section 4.3.2). Hence, it was made clear that there was no need to present oneself especially positively, diligently etc. for reasons connected to students' academic career, for example their grades. And indeed, several students explicitly admitted not to use specific learning offers at all or reported copying as a learning strategy. Both behaviors are commonly considered as rather socially undesirable. Nonetheless, future studies using different methodological approaches are needed to strengthen the present findings or to identify issues of social desirability. Overall, the present results should best be understood as an initial exploration of several (meta-)cognitive, motivational and behavioral aspects of engineering students' self-regulated learning in mathematics courses which provides a basis for researchers to develop and test hypotheses and in general, to deepen and consolidate knowledge in this very under-researched field of research.

4.5.7. Conclusion

This study explored (meta-)cognitive, motivational and behavioral aspects of students' self-regulated learning in mathematics tertiary education. Some findings deserve special attention. Firstly, in several aspects, the current study shed new light on previous findings from mostly quantitative research and conceptual issues such as the definition of mastery-avoidance goals and the inclusion of appearance concerns in performance goals. Secondly, the study clearly demonstrates the importance of the social environment (including instructors such as the professor, and student tutors but also friends and peers) for learning mathematics in tertiary education. Thirdly, the results of the current study show impressively, that students' self-regulated learning in mathematics education is neither homogenous nor stable. Instead, interindividual and in part also intraindividual differences could be observed regarding students' use and evaluation of learning offers, learning strategies with respect to mathematics problems and exam results, achievement goals and attributions for exam results as well as the time spent studying. Thus, attending to students' own descriptions of their self-regulated learning in mathematics tertiary education enables a better understanding of it and provides the foundation to improve it. Future research should continue this endeavor using other methodological approaches and samples.

5. General discussion

This dissertation was inspired by the commonly observed dilemma that mathematics is highly relevant to engineering students both with regards to their future course of study (Dehling et al., 2014; Zimmerman et al., 2011) as well as their future career (Gainsburg, 2015; Harris et al., 2015) but also a really difficult, yet obligatory milestone in their degree programs (Griese, Glasmachers, Härterich, et al., 2011; Rønning, 2014, 2017). Various explanations targeting students as well as instructors and learning environments have been proposed for this problematic situation (see Chapter 1). Since numerous innovations concerning mathematics instruction have already been proposed by other researchers in recent years (e.g. Härterich et al., 2012), in the current study, the focus was laid on students themselves. In particular, self-regulated learning was chosen as the central construct of interest, as it provides an umbrella for many of the existing explanations for students' difficulties with mathematics. The field of self-regulated learning research was encountered to include an overwhelming variety of theoretical models and empirical evidence (see Chapter 2). Yet, several gaps or limitations could be identified which hinder merging respective knowledge and findings with research on mathematics tertiary education or applying them to improve mathematics tertiary education. The current dissertation aimed to tackle these limitations using two different methodological approaches. Yet, both of them are comprehensive in nature and cross the boundaries of singular theories. On the one hand, as described in Chapter 3, a systematic review was conducted in order to provide researchers and practicioners with a structured overview on the current state of research and knowledge in the field of self-regulated learning in mathematics tertiary education, in particular concerning its nature and correlates as well as concerning opportunities to support it. On the other hand, as described in Chapter 4, empirical data were obtained concerning (meta-)cognitive, motivational, and behavioral aspects of engineering students' self-regulated learning in mathematics courses at a German university of technology using semi-structured interviews. For both studies, the specified chapters have already discussed the findings and limitations and outlined their implications for research and practice. In the following closing chapter of this dissertation, main findings are again summarized with respect to the overarching questions and gaps in the literature identified in advance (see Chapter 2). Furthermore, suggestions for research and practice resulting from the interplay of both studies as well as limitations of the dissertation overall are discussed.

5.1. Summary of findings

The first limitation of self-regulated learning research identified was the lack of a systematic summary of research on self-regulated learning in mathematics tertiary education. Such a summary was provided in the current dissertation. More specifically, a systematic review of respective research since the year 2000 was conducted (see Chapter 3). The results provide researchers and practitioners interested in this specific topic with (preliminary) answers to questions about the nature and correlates of self-regulated learning in mathematics tertiary education, and about possibilities to support it. Based on the review, self-regulated learning in mathematics tertiary education can be conceptualized as a dynamic and potentially recursive process which includes different phases and activities that can be distinguished and observed with variable frequency. Associations between mathematics achievement and metacognitive self-regulation, self-efficacy, and time management are relatively well established, although no conclusions regarding the direction or causality of these associations can be drawn based on existing studies. Other correlates of self-regulated learning in mathematics tertiary education identified in the current review included motivational and affective variables (i.e. endogenous perceptions of instrumentality, self-efficacy, enjoyment, pride), demographic characteristics (i.e. nationality or ethnicity) and context or situation variables (i.e. domain, task, or interaction in group work). Furthermore, the review identified several successful interventions to support self-regulated learning, in particular metacognitive aspects and time and study environment management.

Beyond this, the review provided an overview on the current state of research in the field of self-regulated learning in mathematics tertiary education regarding topics addressed, theories used to frame research, definitions of self-regulated learning provided and aspects of self-regulated learning focussed on, research designs and instruments used and target groups studied. Thus, it can serve as a valuable basis for researchers and practitioners when making decisions about how to design their own research, interventions, courses etc. For example, researchers will see that up to now, the theory by Efklides (2011) has not yet been used to frame self-regulated learning research in mathematics tertiary education. This thus is a “blind spot” that might be covered by future research. Similarly, the finding that the effects of self-regulated learning-related trainings or interventions, and phases and temporal sequences of self-, co- and/or socially shared regulation of learning, have received increased attention by researchers in recent years might inspire other researchers to contribute to these emerging lines of research. The overview also contained findings which practicioners might find useful, for example, that the Cyclical Phases of Self-Regulated Learning model by Zimmerman (2000) has not only often been used to study self-regulated learning in the context of mathematics tertiary education, but has also served as a basis for an intervention that was successful in enhancing students’ academic achievement in mathematics courses (Zimmerman et al., 2011).

Two further limitations identified in previous self-regulated learning research concerned the lack of research conducted outside of North America (e.g. Pintrich, 2000b), and the scarcity of research specific to mathematics tertiary education (see Chapter 3 and section 4.1) and engineering students (e.g. Roth et al., 2016; Schmitz & Wiese, 2006). The current dissertation yielded insight into self-regulated learning in mathematics tertiary education in general and that of engineering students in Germany in particular. Thereby, it not only contributes to filling respective gaps in the literature, but it also provides (initial) answers to questions regarding the transferability of existing theories and research to this specific domain, respectively country.

In the interview study conducted with engineering students enrolled in a mathematics course at a German university of technology (see Chapter 4), theories developed in and results retrieved in other countries and domains could be supported in many respects. However, some results, in particular at a lower level of abstraction (i.e. at a subcategory-level) also appeared to be mathematics-, course-, or task-specific. For example, (meta-)cognitive and resource management strategies identified overall could be successfully categorized with a coding scheme developed a priori based on the learning strategies proposed by Wild and Schiefele (1994) for (higher) education in general, and by Liebendörfer and colleagues (Göller et al., 2013; Liebendörfer, 2017; Liebendörfer et al., 2014) for mathematics tertiary education in particular. Both instruments were developed using German samples. However, Liebendörfer and colleagues (Göller et al., 2013; Liebendörfer, 2017; Liebendörfer et al., 2014) adapted the instrument of Wild and Schiefele (1994), who in turn had created their instrument based on the MSLQ (Pintrich et al., 1991), which was developed with American students enrolled in various courses. Nonetheless, using an inductive approach, specific subcategories, respectively learning strategies could be identified that were more mathematics-, course-, or task-specific. For example, whereas metacognitive strategies (in particular planning) were reported by the majority of students with respect to working mathematics problems as well as exam preparation, rehearsal (e.g. re-working mathematics problems) and organizational (e.g. creating a formulary) strategies were found to be more important for exam preparation and elaboration strategies (e.g. using examples) for mathematics problems. Among resource management strategies, effort (e.g. high investment of time), social strategies (e.g. referring to peers and friends in case of difficulties, questions or need of help) and using literature (e.g. lecture slides) were important learning strategies in both situations. In contrast, time management (e.g. making a schedule) was more often reported with respect to exam preparation, whereas the study environment (including learning offers such as tutorials) played a more important role for working mathematics problems.

The goals identified were developed inductively and thus, unique to the current study (see Chapter 4). The most commonly reported specific goal was passing the course and fulfilling one's obligations, followed by acquiring knowledge, understanding or skills in order to be able to apply them during one's studies or as an end in itself. However, as outlined in section 4.5.2.1, these goals aligned relatively well with major theoretical approaches developed in North America (Elliot & Church, 1997; Grant & Dweck, 2003) and empirical results retrieved in other European countries (Anastasakis et al., 2017; Cano & Berbén, 2009; Kaldo & Reiska, 2012). Similarly, although the current study yielded a broad array of attributions, which students made for their exam results, in line with previous findings from other countries, one of the most commonly reported reasons was effort (Anthony, 2000; Maidinsah et al., 2014; Pyzdrowski et al., 2013; Schutz et al., 1998). However, with respect to the time spent studying, results showed that the majority of students reported spending more than six hours per week on studying mathematics during the semester. Thus, the amount of time spent studying was thus higher than that found in previous studies from other countries (Anthony, 2000; Jaworski, 2008) but similar to results of a study conducted in Germany (Laging & Voßkamp, 2016).

Beyond this, the systematic review (see Chapter 3) showed the countries and types of target groups that previous research in the field of self-regulated learning in mathematics tertiary education focused on. Although a tendency towards samples consisting of North American, female and undergraduate (freshmen) Caucasian students could be observed, the review still found a broad diversity among studies concerning aspects such as country where research was conducted, gender ratio, year in college and ethnicity. Thus, researchers and practicioners not only in Germany but also in other countries might find the review a useful starting point to identify research with particular relevance to their research or instructional context and target group. Concerning the domain-specificity of self-regulated learning, the review could not provide a final answer, since studies included in the review targeting this question yielded ambiguous results, which were difficult to compare, because they focused on different constructs and used different methods. Furthermore, even within the studies, differences between contexts, tasks or domains often could be found only in some (types of) analyses, e.g. with process mining (Sobocinski et al., 2017).

The fourth limitation identified in previous research was the dominance of studies using questionnaires to assess self-regulated learning identified in previous research (Dinsmore et al., 2008; Moos & Ringdal, 2012; Roth et al., 2016; Spörer & Brunstein, 2006). The current dissertation provides manifold opportunities for orientation and inspiration for researchers interested in other assessment methods. For example, although the review confirmed the dominance of questionnaires, in particular of the MSLQ (Pintrich et al., 1991), also for the specific field of self-regulated learning research in mathematics tertiary education (see Chapter 3), it further showed, that especially in recent years, other, non-self-report measurement instruments such as observations were used as well.

Furthermore, the empirical study conducted as the second part of this dissertation provides an example for the use of semi-structured interviews to assess (meta-)cognitive, motivational and behavioral aspects of self-regulated learning and their analysis using a deductive-inductive approach oriented on a method for qualitative content analysis described by Kuckartz (2016) (see Chapter 4). It also demonstrated the benefits of this approach, as it allowed for example to provide a very rich and detailed description of the reasons why students did or did not use learning offers, how (often) they used them, and how they evaluated them. For instance, many learning offers were used for exam preparation and working mathematics problems, while other reasons emerged specifically for specific learning offers, such as having a good conscience or a feeling or safety when attending the lecture. Common reasons not to use learning offers included a preference for alternative learning offers or a (perceived) lacking need to use them, whereas an example for a specific reason for non-use were problems with comprehension or attention in lectures. Similarly, the ways in which students used learning offers were very individual for the respective offers, but some similarities could still be detected. For example, learning offers involving contact with instructors were used for asking specific questions, and lectures (live and recordings) were attended to selectively. The qualitative self-report method also allowed to identify self-perceived changes over the course of students' studies regarding the use and appreciation of learning offers (e.g. a decrease of the use of the lecture and an increase of the use of office hours), (meta-)cognitive and resource management learning strategies (e.g. an increasing use of social strategies), and achievement goals (e.g. pursuing application-related goals in addition to (just) passing the course), which were difficult to anticipate in advance due to a scarcity of respective research. Beyond this, the dissertation also provided initial answers to questions related to the adequateness of questionnaires developed based on specific theories to assess students' self-regulated learning in real learning environments. In particular, with respect to learning strategies, as mentioned above, the results of the interview study showed that the overall structure found aligned relatively well with that of questionnaires developed by specific theoretists in the field, in particular Wild and Schiefele (1994) and Pintrich et al. (1991).

5.2. Implications for research

As noted at several points during this dissertation, self-regulated learning is a very broad term and covers a wide range of constructs. This was also reflected in the current dissertation. A review naturally covers all the topics that the reviewed literature addresses. And the interview study addressed (meta-)cognitive, motivational *and* behavioral aspects instead of focusing on just one singular aspect. Due to this variety, the dissertation also provides manifold ideas for further avenues of research. In particular, based on the results of the review (see Chapter 3) and the interview study (see Chapter 4) reported in this dissertation, the author would like to make four suggestions for future research.

Firstly, the author believes that regulation processes in groups or dyads of peers are a very promising area for future research, also specifically in the context of mathematics tertiary education. As the review (see Chapter 3) showed, the theory by Hadwin and colleagues (2018), which describes such regulation processes, has been used in recent years in self-regulated learning research conducted in mathematics tertiary education contexts. To date, existing studies have covered only a limited range of situations in which peer learning occurs. Yet, the interview study (see Chapter 4) clearly demonstrated the importance of peers for students' learning in various situations, for instance when working on mathematics problems or when preparing for exams. Moreover, previous research has shown on the one hand, that (interactions between) peers play an important role in mathematics learning in tertiary education (Griese, 2016), but on the other hand, that teamwork seems to be a challenge in collaborative learning and that students employ different (socially shared) emotion and motivation regulation strategies to overcome this and other challenges (Järvelä & Järvenoja, 2011; Järvenoja, Volet, & Järvelä, 2013). Furthermore, a recent review of meta-analyses (Schneider & Preckel, 2017) demonstrated the importance of social interaction and in particular small group learning for achievement in higher education. Thus, in sum, this area seems to provide opportunities for meaningful research with the chance of finding ways to improve students' experiences and making their learning easier. Yet, researchers should be aware that very different terms have been used in this research field (Hadwin et al., 2011; Panadero & Järvelä, 2015; Schoor et al., 2015). Researchers might find the overviews provided by Hadwin et al. (2018) and Schoor et al. (2015) helpful when trying to find their way through the maze of concepts and terms.

Secondly, the author believes that researchers should continue to explore the context-(in)dependency of self-regulated learning. Self-regulated learning has been conceptualized differently by theorists in this respect (Boekaerts & Corno, 2005; Spörer & Brunstein, 2006). Empirical results are also inconclusive. Whereas some researchers found evidence for context-specificity (e.g. Dent & Koenka, 2016; Greene et al., 2015), other findings were less supportive (Rotgans & Schmidt, 2009). As outlined above (see section 5.1), the current dissertation cannot solve this discussion. However, it might be that the central question is actually one of the right level of abstraction. Even researchers arguing for context-independency suggest that context-specific effects might exist - when searching for them at a level below courses in general (Rotgans & Schmidt, 2009). This is exactly what was done in the interview study presented in the current dissertation (see Chapter 4). Students' were asked about their learning strategies concerning specific situations in mathematics courses, namely working mathematics problems and preparing for exams. And indeed, the learning strategies found were, at least in part, very specific for mathematics or even for the specific course and task. Nonetheless, they could be aggregated and fit into a general classification system for learning strategies developed by Wild and Schiefele (1994). Thus, the author would like to encourage other researchers to continue exploring self-regulated learning in different domains, contexts, tasks etc. to determine, how general or specific self-regulated learning actually is. Especially the models of Winne and Hadwin (1998) and Efklides (2011) provide sufficiently detailed descriptions of self-regulated learning processes which allow to conduct analyses and comparisons at the task-specific level.

Thirdly, based on the results of the current dissertation, particular attention should be given in future research to metacognition as one aspect of self-regulated learning. The review showed that researchers will find a solid literature base to build on (see Chapter 3).

Furthermore, the interview study (see Chapter 4) demonstrated the importance of metacognitive self-regulated learning strategies, in particular when preparing for mathematics exams but also when working mathematics problems. The importance of metacognition is also supported by major theorists in the field of self-regulated learning (e.g. Azevedo, Guthrie, et al., 2004; Greene & Azevedo, 2007; Hadwin et al., 2011; Winne, 2001). Future studies are needed to explore further the role metacognitive self-regulation plays in students' mathematics learning.

Fourthly, the review (see Chapter 3) has provided clear evidence for the supremacy of questionnaires as the measurement instrument of choice among researchers in the field of self-regulated learning in mathematics tertiary education. As mentioned before, this pattern has been observed in other areas of self-regulated learning research as well (Dinsmore et al., 2008; Moos & Ringdal, 2012; Winters et al., 2008). However, questionnaires are not without weaknesses. For example, many questionnaires are not suited to assess situation- or task-specific learning strategies (Roth et al., 2016; Spörer & Brunstein, 2006). Furthermore, it is difficult to determine whether students really use the strategies they indicate (Roth et al., 2016; Spörer & Brunstein, 2006), or, more generally, how students arrive at the rating they make on the scales provided (Winne, 2010). The interview study conducted in this dissertation (see Chapter 4) contradicts the general trend to use questionnaires to assess self-regulated learning in mathematics tertiary education and demonstrated that semi-structured interviews can be successfully used in this research field. Yet, as the review showed, interviews are but one of several methodological alternatives. Another interesting method, which according to the review has received increasing attention during the last years, are observations, in particular video recordings of students' collaborative work (e.g. Järvelä et al., 2016; Malmberg et al., 2017; Sobocinski et al., 2017) or observation of instruction (e.g. Hoops et al., 2016). The author believes that such an approach would be especially suitable to explore the regulatory processes occurring in peer groups while learning mathematics in other settings than those studied up to now. For example, mathematics tutorials or inofficial learning groups could be interesting contexts for future research. If researchers however decide to use a questionnaire, they are strongly advised to use the MSLQ (Pintrich et al., 1991), as it is the most commonly used questionnaire in the field of self-regulated learning research, both specifically concerning mathematics tertiary education (see section 3.4.1) and in general (see for example Roth et al. (2016)).

5.3. Implications for practice

Supporting students' self-regulated learning should be a central aim of education at any level (Puustinen & Pulkkinen, 2001). The author believes that this dissertation has the potential to support practicioners involved in designing and realizing mathematics tertiary education in coming closer to achieving this goal. Ideas for opportunities to transfer the findings of the two studies into practice have already been presented in the respective sections (see sections 3.5.5 and 4.5.5). However, some general implications for practice which should be brought to the reader's attention will be explained further in the following.

Firstly, based on the current dissertation, practicioners are strongly encouraged to think of ways how to integrate self-regulated learning-related trainings into curricula and courses. The review (see Chapter 3) showed that various trainings have already been developed and implemented in mathematics courses in different countries and at different types of institutions. Although these trainings might not be suitable to be directly introduced into a particular course or curriculum, they can provide practitioners with ideas on how to realize them at their specific institution. Furthermore, the description of engineering students' self-regulated learning in mathematics courses provided in the current dissertation (see Chapter 4) can support practitioners with further hints concerning the areas and strategies to focus on.

Secondly, beyond specific trainings, it is hoped that instructors are inspired by this dissertation to reflect on the teaching practices they use in everyday classroom-situations. The review (see Chapter 3) identified several studies which have investigated the effects of different teaching methods. Furthermore, with the study of Hoops et al. (2016), it provided an instrument instructors might use to observe their teaching practices and thus, to support the reflection process. As additional motivation should serve the results of the interview study (see Chapter 4), according to which learning offers and instructors play an important role for students when learning mathematics (i.e. when working mathematics problems or preparing for exams) and are also perceived as playing an important role for achievement outcomes.

Thirdly, the author can only concur with similar calls of other researchers (Cornford, 2002; Landmann, Perels, Otto, & Schmitz, 2009; Panadero, 2017) that instructors should be trained regarding self-regulated learning in order to provide them with the knowledge and skills they need to train their students in turn. This implies that self-regulated learning theories and trainings should be included not only in education of prospective school teachers but also in trainings for instructors in higher education.

Fourthly, both studies presented in this dissertation support the existence of interindividual and intraindividual differences concerning self-regulated learning in mathematics tertiary education (see Chapters 3 and 4). Thus, instructors should be aware of the diversity inherent in their courses and the potential consequences for the effectiveness of mathematics instruction as well as self-regulated learning trainings.

5.4. Limitations

Limitations of the two studies included in this dissertation have already been discussed extensively in the respective chapters (see section 3.5.6 and 4.5.6). In the following, some overarching limitations of this dissertation will be discussed, including the potential avenues for future research to address them.

Firstly, although obvious and logical due to the topic of the current dissertation, both studies only focussed on self-regulated learning in mathematics tertiary education. As discussed above, it remains to be determined if and at which level of abstraction self-regulated learning is domain-specific (see section 5.2). Thus, it is unclear to what extent the results of the interview study (see Chapter 4) could be replicated in other learning contexts or domains. In the case of the review (see Chapter 3), in any case, there is a need for systematic summaries of the current state of knowledge concerning self-regulated learning in other educational areas or domains. For some, such as computer-based learning environments (Winters et al., 2008), such summaries already exist, whereas for others they need to be realized by future research (see section 3.1 for an overview on existing reviews in the field of self-regulated learning research). Thus, in general, it can be stated that future research should try to extend the findings of the current dissertation to other educational levels and domains.

Secondly, both methodological approaches taken in the current study (see Chapters 3 and 4) did not allow to test for the significance of observed trends and effects (e.g. trends in topics targeted over the years, changes concerning students' learning strategies over the course of their studies etc.). As explained in the subsections discussing the limitations of the studies (see section 3.5.6 and 4.5.6), in both cases, such an approach was deemed inappropriate or even impossible due to the existing database. Nonetheless, future studies could derive specific research questions or hypotheses from the findings presented in the current dissertation and test them, for example with a meta-analysis or a mixed-methods study.

Thirdly, and somewhat connected to the argument before, the current dissertation did not allow to assess the potential effects of students' characteristics such as age, degree program, gender or ethnicity. With regards to the review (see Chapter 3), as mentioned in the respective discussion (see section 3.5), such an analysis was precluded not only by the methodological approach (i.e. review instead of meta-analysis), but also by the fact that researchers reported respective information in varying formats or not at all. With regards to the interview study (see Chapter 4), respective analyses could not be made due to ethic and data privacy issues. Therefore, future studies are needed to overcome this limitation and enrich knowledge about the role such characteristics play for students' self-regulated learning in mathematics tertiary education.

5.5. Conclusion

To conclude, this dissertation has addressed self-regulated learning in mathematics tertiary education both on a rather theoretical, literature-based as well as on an empirical plane. Given that self-regulated learning skills are important not only in higher education but also beyond, for example in the working environment and are necessary for lifelong learning (Cornford, 2002; Spinath et al., 2012) and that mathematics plays an important role in many occupations including engineering (Gainsburg, 2015; Harris et al., 2015), this endeavor was timely and needed. The findings of this dissertation advance understanding of the current state of research on self-regulated learning in mathematics tertiary education and provide in-depth insights into various aspects of engineering students' self-regulated learning in mathematics courses at a German university of technology. Still, future research is needed to enrich the sketch of self-regulated learning in mathematics tertiary education provided in this dissertation. Furthermore, the results of this dissertation have the potential to be transformed into interventions beneficial for students enrolled in mathematics courses in higher education. Based on the results of this dissertation, there is evey reason to believe that (engineering) students possess important self-regulated learning skills relevant for mathematics education and that these skills can be successfully promoted by interventions. It is now up to practicioners to find ways how to best realize learning environments supportive to self-regulated learning. Overall, the author hopes that the current dissertation will serve as an inspiration and basis for researchers and practicioners to further engage in researching, respectively supporting self-regulated learning, especially in mathematics tertiary education.

6. References

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7. Appendix

7.1. Coding sheet for literature search

Coding Category	Coding Rule
General information	
Name of the author(s)	Open Coding.
Publication year	Open Coding.
Name of the journal	Open Coding.
Topic	
Research question or hypothesis	Open Coding. Code only the most precise and explicit statement.
Aspect of SRL focused on *Cognitive* *Metacognitive* *Motivational* *Affective* *Behavioral*	Selection between: Yes; no; unknown for each aspect and open coding of specific constructs. Selection of multiple aspects possible. Coding based on author(s) description, if none available, judgement oriented on framework of Pintrich (2004).
Definition type	Selection between: Explicit; implicit. Coding oriented on the work by Dinsmore et al. (2008) and Murphy and Alexander (2000). Coding of "explicit" only, when the author(s) explicitly give(s) a personal definition of self-regulated learning or explicitly states that a particular theoretical framework, definition etc. of other researchers was adopted.
Implicit definition type	Selection between: Conceptual; referential; conceptual & referential; measurement. Coding oriented on the work by Dinsmore et al. (2008) and Murphy and Alexander (2000). Coding of "conceptual" if author(s) elaborate(s) on the concept without explicitly stating or appropriating a definition or theoretical framework. Selection of "conceptual" also if the elaboration contains references to works of other researchers but no specific position is highlighted. Coding of "referential" if author(s) refer(s) to works of specific researchers without elaborating on their work, e.g. if the author(s) use(s) short citations. Coding of "conceptual & referential" if author(s) refer(s) to works of specific researchers and elaborates on their work. Coding of "measurement" if the measurement provides the only information on how the construct was defined. Selection only when no other category applies.
Theory	
Theory *Azevedo et al. (Azevedo, Guthrie, et al., 2004)* *Boekaerts et al. (Boekaerts, 1991, 1996; Boekaerts & Corno, 2005)* *Efklides (2011)* *Hadwin et al. (Hadwin et al., 2018)* *Pintrich (Pintrich, 2000b; Pintrich et al., 1991)* *Schmitz et al. (Schmitz & Wiese, 2006)* *Winne et al. (Winne & Hadwin, 1998)* *Wolters (2003)* *Zimmerman (Zimmerman, 1989, 2000; Zimmerman & Martinez Pons, 1986)*	Selection between: Yes; no for each theory. Selection of multiple theories possible. Coding only for those theories on which research and/or argumentation builds, not for those mentioned only peripherally.

Specific Theory	Categories available for selection depend on researcher/ research group. Selection of multiple theories possible. Coding based on the review by Panadero (2017) and information provided by the author(s).
Integration of theory	Selection between: Explicitly stated; cited; measure. Coding of “explicitly stated” when author(s) explicitly mention(s) to build on a theory. Coding of “cited” when the author(s) make(s) references to a theory. Coding of “measurement” when the measurement instrument used belongs to a specific research tradition and no other category applies.
Research design & instruments	Coding only for those research questions & analyses relevant to self-regulated learning.
Data basis	Selection between: Primary analysis; secondary analysis; meta-analysis. Coding based on the criteria described by Döring and Bortz (2016). Coding based on the information given by the author(s). Coding of “primary analysis” if data are collected and analyzed for the reviewed study. Coding of “secondary analysis” if data are re-analyzed for the reviewed study. Coding of “meta-analysis” if results from several previous studies are summarized in a meta-analytic procedure.
Experimental design	Selection between: Experimental study; quasi-experimental study; non-experimental study. If multiple categories apply, the category applying to the majority of research questions & analyses is selected. Coding based on the criteria described by Döring and Bortz (2016). Coding of “experimental study” if groups are created randomly and the independent variable(s) is/are manipulated systematically by the researcher(s). Coding of “quasi-experimental study” if groups are not created randomly and the independent variable(s) is/are manipulated systematically by the researcher(s). Coding of “non-experimental study”, if groups are not created randomly and the independent variable(s) is/are not manipulated systematically by the researcher(s).
Place of study	Selection between: Laboratory study; field study; unknown. If multiple categories apply, the category applying to the majority of research questions & analyses is selected. Coding based on the criteria described by Döring and Bortz (2016). Coding of “laboratory study” if study was conducted in a controllable environment Coding of “field study” if study was conducted in a natural environment with reduced opportunities for control. Coding of “unknown” if not enough information was available to decide upon the place of study.
Measurement points	Selection between: Independent measures or between-subjects design; repeated measures or within-subjects design; cross-sectional study; trend study; longitudinal study. If multiple categories apply, the category applying to the majority of research questions & analyses is selected. Coding based on the criteria described by Döring and Bortz (2016). Coding of “independent measures or between-subjects design” if a (quasi-)experimental study had only one measurement point after the intervention and used different participants for the different groups Coding of “repeated measures or within-subjects design” if a (quasi-)experimental study had several measurement points (i.e. a pre-post-measurement) and/or subjected the same participants to several experimental or control treatments. Coding of “cross-sectional study” if one sample is assessed once with a particular measurement instrument in a non-experimental study or if no changes/temporal developments are investigated Coding of “trend study” if several cross-sectional studies are conducted at different points in time to investigate changes/temporal developments, using the same measurement instrument but different samples. Coding of “longitudinal study” if the same sample is assessed more than once with the same measurement instrument to investigate changes/temporal developments in a non-experimental study.

Type of assessment instrument for SRL *Questionnaire* *Observation* *Interview* *Think Aloud* *Diary* *Traces* *Test* *Judgment of others*	Selection between: Yes; no for each assessment instrument. Code only those instruments used for analysis. Selection of multiple assessment instruments possible.
Specific assessment instrument for SRL	Categories available for selection depend on assessment instrument. Coding also if (parts of) an instrument available for selection is/are used in combination with (parts of) an instrument not available for selection.
Quality of assessment instrument for SRL	Selection between: Established measure; adapted established measure; non-established measure; non-established adapted measure; self-constructed measure. Coding oriented on the work by Dent and Koenka (2016). Coding of "established", if instrument occurs in the predefined selection for specific assessment instruments. Coding also if (parts of) an established instrument is/are used in combination with (parts of) a non-established or self-constructed instrument. Coding of "non-established", if instrument was not self-constructed but does not fulfil the criteria for "established". Coding of "adapted" e.g. when items were rephrased or only some parts (e.g. subscales) of a measure used.
Alignment of assessment instrument for SRL with theory	Selection between: Full alignment; partial alignment; ill alignment; not applicable. Coding inspired by the work by Dinsmore et al. (2008). Coding "full alignment" if measurement instrument(s) stems from same research tradition as theory/theories framing research and/or align(s) well with the definition of self-regulated learning provided. Coding "Partial alignment" if measurement instrument is aligned with one of several theories framing research or if one of several measurement instruments is in alignment with the theory framing research and/or if measurement instrument(s) only partially align(s) with the definition of self-regulated learning provided. Coding "Ill alignment" if there is no alignment between the measurement instrument(s) and the definition of self-regulated learning provided or the theory/theories framing research. Coding "Not applicable" if there are no rating can be made, e.g. due to lacking information
Target group	In case of several samples for which separate analyses were conducted on purpose or due to the design, information was coded for all samples.
Country where research was conducted	Open Coding. If no specific information available, if possible and consistent, use information on institution of authors, otherwise code as "unknown".
Institution type	Selection between: Public; private; unknown. Coding based on the work of Dent and Koenka (2016). Coding of community colleges in the U.S. as "public"
Size	Open Coding. If possible, use information for final sample for analyses.
Dimension	Selection between: small (N <100); medium (100 ≤ N ≥ 400); large (N > 400). Coding based on the work of Roth et al. (2016). If possible, use information for final sample for analyses.
Average Age	Open Coding. Coding based on the work of Dent and Koenka (2016). If possible, use information for final sample for analyses.
Median Age	Open Coding. Coding based on the work of Dent and Koenka (2016). If possible, use information for final sample for analyses.
Age Range	Open Coding. Coding based on the work of Dent and Koenka (2016). If possible, use information for final sample for analyses.
Gender ratio	Open Coding. If possible, use information for final sample for analyses. Coding of the percentage of males in the sample.

Year in college *Prospective students* *1st / freshmen* *2nd / sophomore* *3rd / junior* *4th / senior* *Graduate students*	Selection between: Yes; No; Unknown for each group. Selection of multiple groups possible. If possible, use information for final sample for analyses.
Degree program / major	Open Coding. If possible, use information for final sample for analyses.
Degree program category	Selection between: STEM; non-STEM; mixed; unknown. If possible, use information for final sample for analyses.
Ethnicity	Open Coding. If possible, use information for final sample for analyses.
Special characteristics	Open Coding. If possible, use information for final sample for analyses.
Results & Other	
Main Results	Open coding.

Note. STEM = science, technology, engineering and mathematics; SRL = self-regulated learning.

7.2. Category system for research questions

Category	Definition	Example
Effects of SRL-related trainings & interventions	Research questions / hypotheses referring to the effects of trainings of SRL, respectively interventions aimed at improving SRL	
Effects on SRL knowledge & behavior	Effects on SRL knowledge and/or behavior	Bellhäuser et al. (2016)
Effects on mathematics achievement	Effects on mathematics achievement	Hudesman et al. (2014)
Effects on other variables	Effects on other variables (i.e. they are not subsumed under SRL by the author(s) of the article and/or the author of this dissertation)	Acee and Weinstein (2010)
Association between SRL / SSRL & mathematics achievement	Research questions / hypotheses referring to the relationship between SRL or SSRL and mathematics achievement.	Cho and Heron (2015)
Association between SRL & other variables	Research questions / hypotheses referring to the relationship between SRL and other variables (i.e. they are not subsumed under SRL by the author(s) of the article and/or the author of this dissertation)	Husman and Hilpert (2007)
Domain & context dependency of SRL	Research questions / hypotheses referring to the variability/ constancy of SRL across different academic domains or situations	Rotgans and Schmidt (2009)
Ethnic & cultural differences concerning SRL / SSRL	Research questions / hypotheses referring to differences/ similarities concerning SRL or SSRL between different ethnic groups or groups from different nations	Shi et al. (2013)
Phases & temporal sequences of SRL / CORL / SSRL	Research questions / hypotheses referring to the development of SRL, CORL or SSRL over time (including the identification of patterns of activities, phases etc.) or to specific phases of SRL	Malmberg et al. (2017)
Other – SRL related	Research questions / hypotheses referring to other SRL-related topics	Hoops et al. (2016)

Note. CORL = co-regulated learning; SRL = self-regulated learning; SSRL = socially shared regulation of learning.

7.3. Additional tables for study 1

Table 18

Theories used as basis for research and/or argumentation (extended version)

Theory	M	C	E	O	Article
Azevedo et al. (Azevedo, Guthrie, et al., 2004)	0	1	1	2	Shi et al. (2013); Sobocinski et al. (2017)
Boekaerts et al.	0	4	0	4	
Six-component model of SRL (Boekaerts, 1996)	0	1	0	0	Schoor and Bannert (2012)
Adaptable Learning model (Boekaerts, 1991)	0	1	0	1	Hauk (2005)
Dual Processing SR Model (Boekaerts & Corno, 2005)	0	2	0	0	Cho and Heron (2015); Villavicencio and Bernardo (2013)
Efklides (2011)	0	0	0	0	
Hadwin et al. (2018)	0	2	1	3	Järvelä et al. (2016); Malmberg et al. (2017); Sobocinski et al. (2017)
Pintrich	6	9	1	16	
Framework (Pintrich, 2000b)	0	5	1	6	Acee and Weinstein (2010); Cho and Heron (2015); Fong et al. (2015); Hoops et al. (2016); Talbert (2015); Villavicencio and Bernardo (2016)
MSLQ (Pintrich et al., 1991)	6	4	0	10	Bellhäuser et al. (2016); Bol et al. (2016); Davaanyam and Tserendorj (2015); Dunn (2014); Hodges and Kim (2010); Husman and Hilpert (2007); Järvelä et al. (2016); Muis (2008); Rotgans and Schmidt (2009); Villavicencio and Bernardo (2013)
Schmitz and colleagues (Schmitz & Wiese, 2006)	0	0	1	1	Bellhäuser et al. (2016)
Winne et al. (Winne & Hadwin, 1998)	0	8	3	11	Cho and Heron (2015); Hadwin et al. (2005); Hoops et al. (2016); Järvelä et al. (2016); Malmberg et al. (2017); Muis (2008); Schoor and Bannert (2012); Sobocinski et al. (2017); Winne and Muis (2011); Zientek et al. (2013); Zimmerman et al. (2011)
Wolters (2003)	0	2	0	2	Acee and Weinstein (2010); Hoops et al. (2016)
Zimmerman	0	10	8	18	
Cyclical Phases of SRL (Zimmerman, 2000)	0	6	7	13	Acee and Weinstein (2010); Bol et al. (2016); Cho and Heron (2015); Cifarelli et al. (2010); Fong et al. (2015); Hoops et al. (2016); Hudesman et al. (2014); Järvelä et al. (2016); Malmberg et al. (2017); Schoor and Bannert (2012); Shi et al. (2013); Sobocinski et al. (2017); Zimmerman et al. (2011)
Triadic Analysis of SRL (Zimmerman, 1989)	0	4	2	6	Cifarelli et al. (2010); Hadwin et al. (2005); Hodges and Kim (2010); Hoops et al. (2016); Loong (2012); Rotgans and Schmidt (2009)
Multi-Level model of SRL (Zimmerman, 2000)	0	1	0	1	Hadwin et al. (2005)
SRLIS (Zimmerman & Martinez Pons, 1986)	0	1	0	1	Zientek et al. (2013)

Note. M = measurement; C = cited; E = explicitly stated; O = overall; MSLQ = Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991); SR = self-regulation; SRL = self-regulated learning; SRLIS = Self-Regulated Learning Interview Schedule (Zimmerman & Martinez Pons, 1986). Displayed are the number of articles belonging to the category.

Table 19

Definition type used relative to number of theories used as basis for research and/or argumentation

	Number of theories	
Definition type	1	>1
Explicit	3	11
Implicit	7	7

Note. Displayed are the number of articles belonging to a specific category.

Table 20

Number of theories explicitly stated relative to number of theories used as basis for research and/or argumentation

	Number of theories used	
Number of theories explicitly stated	1	>1
0	8	7
1	2	9
2	0	2

Note. Displayed are the number of articles belonging to a specific category.

Table 21

Alignment between theory and measurement relative to number of theories used as basis for research and/or argumentation

	Number of theories	
Alignment	1	>1
Not applicable	1	1
Ill	1	3
Partial	4	4
Full	4	10

Note. Displayed are the number of articles belonging to a specific category.

7.4. Interview Guideline[1]

LEARNING

A1. How do you study for mathematics?

- Which learning offers *[Explanation: lecture, tutorial,…]* do you use?
  - How do you use them?
  - When do you use them?
  - For what purposes do you use them?
  - How helpful do you find them?
    - Why are they helpful?
  - Why don't you use the following learning offers? *[lecture, lecture recordings, tutorial, mathematics problems, video tutorials]*
- How much time per week do you spend on mathematics?
  - During the semester/ during semester break
- Did it change over the course of your studies how you study for mathematics?

A2.[2] How do you proceed when you work on mathematics problems?

- How do you start? How exactly do you proceed further step-by-step?
- And how do you react if you (still) experience difficulties when working on mathematics problems? *[if no (further) strategies can be described]*
- You have reported that you do various things while working on mathematics problems, for example […]. How often do you do these individual things? *[very seldom, now and then, sometimes, very often, always]*
- Did your procedure for working mathematics problems change over the course of your studies?

A3.[2] How do you proceed when you prepare for a mathematics exam?

- How do you start? How exactly do you proceed further step-by-step?
- And how do you react if you (still) experience difficulties when preparing for the exam? *[of no (further) strategies can be described]*
- You have reported that you do various things while preparing for an exam, for example […]. How often do you do these individual things? *[very seldom, now and then, sometimes, very often, always]*
- Did your procedure for preparing for a mathematics exam change over the course of your studies?

A4. What is the course about for you?

- Did that change over the course of your studies?

LEARNING SUCCESS

B1.[3] How do you rate your learning success in the courses which you have attended so far?

- How did it go in the exams?
  - How satisfied were you with your exam results?
  - From your point of view, what are the reasons for failing the exam / the bad results / good results /… *[depending on results and satisfaction]*?
    - Did personal learning prerequisites / general life situation / instructors / course design / learning behavior play a role?

FINISH

C1. Did we forget something that you would like to address?

[1] Please note: The guideline presented here is a translated version of the original German guideline, which can be obtained from the author of this dissertation. Passages in cursive are additional information for the interviewer.

[2] Adapted from Spörer (2003)

[3] Oriented on the model by Helmke and Schrader (2006)

7.5. Questionnaire[4]

Age		
Gender		
Degree program		
Semester		
Last score in mathematics in school (grade in the Abitur, respectively course)		
So far, I have attended the following mathematics courses:		Grade:
		Grade:
		Grade:
		Grade:

[4] Please note: The questionnaire presented here is a translated version of the original German questionnaire, which can be obtained from the author of this dissertation.

7.6. Additional tables for study 2

Table 22

Learning strategies for exam preparation

category	*n*	%
Effort	25	92.59
Effort	25	92.59
Already during the semester	15	55.56
General	5	18.52
High investment of time	13	48.15
Manifold problem solving attempts	3	11.11
Working mathematics problems	17	62.96
No effort	11	40.74
Giving up in case of difficulties	4	14.81
Limited effort / investment of time	9	33.33
Elaboration strategies	9	33.33
Other	3	11.11
Scaling down	2	7.41
Using examples	5	18.52
Literature	26	96.30
Books / specialist literature	2	7.41
Internet	6	22.22
Lecture notes	4	14.81
Lecture recordings	5	18.52
Lecture slides	11	40.74
Contents & information	9	33.33
General	3	11.11
In case of difficulties	2	7.41
Mathematics problems & solutions	16	59.26
Other e-learning offers	10	37.04
Personal notes & summaries	6	22.22
Video tutorials	12	44.44
General	10	37.04
Refreshment of topics	4	14.81
Metacognitive strategies	27	100.00

Controlling	19	70.37
Assessing comprehension / learning	13	48.15
Comparing / correcting mathematics problems	9	33.33
Solving under time pressure / test conditions	4	14.81
Planning	27	100.00
Procedure	14	51.85
Scope / content	21	77.78
Identifying exam-relevant topics & tasks	14	51.85
Narrowing down topics & tasks	17	62.96
Sequence	13	48.15
Reacting	18	66.67
Adapting / proceeding with learning strategies / learning behavior	13	48.15
Using learning offers	5	18.52
Working additional mathematics problems	6	22.22
Working mathematics problems again / repeating	4	14.81
Organizational strategies	20	74.07
Creating summaries	17	62.96
Formulary	15	55.56
General	8	29.63
Identifying important content	12	44.44
Searching resources purposefully	9	33.33
When working on mathematics problems	3	11.11
Rehearsal	27	100.00
Rehearsing	27	100.00
Exam preparation problems	10	37.04
General	11	40.74
Mathematics problems already worked	23	85.19
Mathematics problems during semester	12	44.44
Old exam problems	21	77.78
Other mathematic problems	10	37.04
Repeating contents	4	14.81
Using resources repeatedly	4	14.81
Social strategies	25	92.59
Friends & peers	18	66.67

Comparing solutions	8	29.63
Explaining to others	3	11.11
General	3	11.11
In case of difficulties / questions / need of help	12	44.44
Working mathematics problems together	4	14.81
Instructors	8	29.63
Professor	5	18.52
Tutors	4	14.81
Learning offers	18	66.67
Lecture, tutorial & mathematics problems	7	25.93
Office hours	9	33.33
In case of difficulties	7	25.93
General / comprehension	3	11.11
Other e-learning offers	3	11.11
Other face-to-face offers	8	29.63
Demonstration of problem solving / examples	6	22.22
Identification & summary of important topics	4	14.81
In case of difficulties / explanations	5	18.52
Older students	2	7.41
Others	4	14.81
Study environment	7	25.93
At home	2	7.41
University spaces	5	18.52
Time management	25	92.59
Becoming more efficient	3	11.11
Concrete planning of time	23	85.19
Schedule	12	44.44
Time available	8	29.63
Time needed	7	25.93
Time spent	13	48.15
Time pressure / limited time	6	22.22
Understanding theory	3	11.11
Working alone	6	22.22

Note. Reported are only categories with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy at least once.

Table 23

Learning strategies for working mathematics problems

Category	*n*	%
Copying	5	18.52
Effort	26	96.30
Effort	25	92.59
Attending learning offers	11	40.74
Despite difficulties	5	18.52
High investment of time	12	44.44
Working mathematics problems	14	51.85
No effort	18	66.67
Giving up due to lacking exam relevance / importance	5	18.52
Giving up due to time investment needed	6	22.22
Giving up in case of difficulties	7	25.93
Limited investment of time	4	14.81
Elaboration strategies	18	66.67
Linking with general knowledge	5	18.52
Linking with knowledge from lecture	7	25.93
Applying sentences & methods	5	18.52
General	2	7.41
Linking with knowledge from tutorial	5	18.52
Using examples	15	55.56
Comprehension	6	22.22
General	4	14.81
In case of difficulties	8	29.63
Replicating / adapting / orienting	7	25.93
Literature	24	88.89
Books / specialist literature	3	11.11
Formulary	2	7.41
Internet	10	37.04
Lecture notes	7	25.93
Lecture recordings	6	22.22
Lecture slides	17	62.96
Examples	7	25.93

General	7	25.93
In case of difficulties	6	22.22
Information	10	37.04
Other	3	11.11
Personal notes & summaries	2	7.41
Sample solutions	13	48.15
Control	2	7.41
Examples	9	33.33
In case of difficulties	5	18.52
Video tutorials	9	33.33
Comprehension	5	18.52
In case of difficulties	6	22.22
Metacognitive strategies	19	70.37
Controlling	10	37.04
Office hours	2	7.41
Peers	6	22.22
Sample solutions	4	14.81
Planning	13	48.15
Procedure	3	11.11
Scope	5	18.52
Sequence	4	14.81
Task analysis	6	22.22
Timing	2	7.41
Reacting	4	14.81
Working of repeated / additional mathematics problems	4	14.81
Motivation	2	7.41
Organizational strategies	4	14.81
Purposeful task identification	4	14.81
Rehearsal	4	14.81
Rehearsing	4	14.81
Social strategies	27	100.00
Friends & peers	22	81.48
Attending learning offers together	4	14.81
Comparing & discussing solutions	6	22.22

Helping others	3	11.11
In case of difficulties / questions / need of help	19	70.37
Working mathematics problems together	10	37.04
Instructors	10	37.04
Learning offers	27	100.00
Lecture	5	18.52
Hints / information / explanations / tips & tricks	3	11.11
In case of difficulties / questions / need of help	3	11.11
Office hours	14	51.85
Controlling & correcting solutions	3	11.11
In case of difficulties / questions / need of help	13	48.15
Other face-to-face offers	5	18.52
Tutorials	23	85.19
Hints / information / explanations / tips & tricks	15	55.56
In case of difficulties / questions / need of help	20	74.07
Others	7	25.93
Study environment	25	92.59
At home	9	33.33
Learning offers	23	85.19
Office hours	4	14.81
Tutorials	23	85.19
Technology	3	11.11
University spaces	5	18.52
Time management	14	51.85
Concrete planning of time	9	33.33
Time pressure	9	33.33
Trying different approaches	3	11.11
Working alone	15	55.56

Note. Reported are only categories with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy at least once.

Table 24

Attributions for exam results

Category	*n*	%
Ability/ knowledge / comprehension	9	33.33
Comprehension	6	22.22
Previous / background knowledge	6	22.22
Available time for learning	6	22.22
Effort	24	88.89
General	14	51.85
Investing time	7	25.93
Rehearsing / working mathematics problems	13	48.15
Exam behavior	8	29.63
General	2	7.41
Mistakes	6	22.22
Exam construction	10	37.04
Instructors	24	88.89
Assistant	3	11.11
Exam construction	2	7.41
General	2	7.41
General	3	11.11
Professor	19	70.37
Attitude / impression	6	22.22
Exam construction	6	22.22
General	2	7.41
Motivation	2	7.41
Teaching methods	10	37.04
Tutor	9	33.33
Help / support	4	14.81
Other	2	7.41
Teaching methods	4	14.81
Learning behavior	14	51.85
General	5	18.52
Identifying / focussing on exam relevant contents	7	25.93
Specific behaviors	5	18.52
Solving under time pressure	2	7.41

Learning offers	22	81.48
Availability of offers	4	14.81
General	2	7.41
Lecture	5	18.52
Lecture notes	2	7.41
Mathematics problems	6	22.22
Office hour	5	18.52
Other e-learning offers	3	11.11
Other face-to-face offers	8	29.63
Tutorial	11	40.74
Luck	5	18.52
Motivation	11	40.74
Interest	5	18.52
Motivation / attitude	6	22.22
Nervousness	5	18.52
Peers	2	7.41

Note. Reported are only categories with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy at least once.

Table 25

Reasons for using learning offers (extended version)

Category	*n*	%
Lecture	18	66.67
Exam preparation	7	25.93
Examples	6	22.22
Feeling of safety / good conscience	3	11.11
Instructor	5	18.52
Introduction to topics / methods / contents	8	29.63
Other	5	18.52
Working mathematics problems	5	18.52
Lecture notes	10	37.04
Dealing with contents	4	14.81
Exam preparation	4	14.81
Working mathematics problems	8	29.63
Lecture recordings	15	55.56
Comprehension (problems)	3	11.11
Exam preparation	5	18.52
Replacement / review of lecture	5	18.52
Supplementing lecture slides	7	25.93
Working mathematics problems	6	22.22
Lecture slides	24	88.89
Comprehension / content	3	11.11
Exam preparation	11	40.74
Replacement / review of lecture	6	22.22
Working mathematics problems	20	74.07
Examples	9	33.33
Formulas, methods & solution strategies	12	44.44
General	12	44.44
Mathematics problems	27	100.00
Comprehension / learning	11	40.74
Exam bonus	15	55.56
Exam preparation	27	100.00
General	25	92.59

Identifying relevant contents & typical tasks	6	22.22
Other	2	7.41
Office hour	18	66.67
Exam preparation	8	29.63
Learning mathematics / comprehension	7	25.93
Working mathematics problems	16	59.26
Asking questions / receiving help & explanations	16	59.26
Checking & correcting mathematics problems	3	11.11
General	4	14.81
Old exams & exam preparation problems	25	92.59
Exam preparation	25	92.59
General	24	88.89
Identifying relevant contents & typical tasks	6	22.22
Other e-learning offers	12	44.44
Exam preparation	12	44.44
Other face-to-face offers	13	48.15
Exam preparation	9	33.33
Learning mathematics / comprehension	3	11.11
Working mathematics problems	6	22.22
Sample solutions	15	55.56
Exam preparation	5	18.52
Working mathematics problems	13	48.15
Exemplary procedure	6	22.22
General	4	14.81
In case of difficulties	6	22.22
Tutorial	26	96.30
Applying theory	2	7.41
Exam preparation	4	14.81
Learning mathematics / comprehension	9	33.33
Other	2	7.41
Submitting and collecting mathematics problems	2	7.41
Working mathematics problems	25	92.59
Asking questions / receiving help & explanations	22	81.48
General	20	74.07

Video tutorials	21	77.78
Exam preparation	12	44.44
(Checking) solutions	3	11.11
Explanations & procedures	5	18.52
General	5	18.52
Important contents	2	7.41
Refreshing memory	4	14.81
Introduction to problem solving methods	10	37.04
Other	2	7.41
Working mathematics problems	6	22.22

Note. Reported are only categories with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy at least once.

Table 26

Ways of using learning offers (extended version)

Category	*n*	%
Lecture	13	48.15
Asking questions	3	11.11
Listening only	3	11.11
Paying attention selectively	3	11.11
Preparation / review	5	18.52
Taking notes	4	14.81
Lecture recordings	5	18.52
Keeping in readiness	2	7.41
Selective use	2	7.41
Taking notes	2	7.41
Lecture slides	10	37.04
Creating a summary	6	22.22
During the tutorial	8	29.63
Mathematics problems	21	77.78
Peers	13	48.15
Copying	5	18.52
Help / working together / comparing solutions	12	44.44
Working alone	16	59.26
Office hour	8	29.63
Asking specific questions	8	29.63
Old exams & exam preparation problems	8	29.63
Peers	7	25.93
Solving under time pressure	2	7.41
Tutorial	17	62.96
Asking specific questions	6	22.22
Collaboration with peers	8	29.63
Several peer week	8	29.63

Note. Reported are only categories with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy at least once.

Table 27

Reasons for non-use of learning offers (extended version)

Category	*n*	%
Lecture	16	59.26
Comprehension / attention difficulties	6	22.22
Date / frame conditions	3	11.11
Lacking relevance for exam	5	18.52
Not useful / sensible	3	11.11
Other	3	11.11
Other academic obligations	2	7.41
Preference for dealing with contents on one's own	5	18.52
Preference for other learning offers	9	33.33
Lecture slides & recordings	4	14.81
Office hours	2	7.41
Tutorials	5	18.52
Lecture notes	4	14.81
Preference for other learning offers	4	14.81
Lecture slides	4	14.81
Lecture recordings	14	51.85
Lacking need	10	37.04
Attending lectures	4	14.81
Lecture slides sufficient	5	18.52
Other	2	7.41
Other	2	7.41
Preference for other learning offers	6	22.22
Lecture slides	3	11.11
Mathematics problems	2	7.41
Other	2	7.41
Mathematics problems	6	22.22
Lacking capacity / time	3	11.11
Lacking relevance for exam	3	11.11
Office hour	9	33.33
Lacking need	2	7.41
Lacking time	3	11.11

Not useful / sensible	4	14.81
Preference for other learning offers	3	11.11
Old exams & exam preparation problems	6	22.22
Lacking solution	2	7.41
Overlap with other learning offers	2	7.41
Preference for other learning offers	2	7.41
Other e-learning offers	2	7.41
Not useful / sensible	2	7.41
Other face-to-face offers	4	14.81
Date / frame conditions	2	7.41
Other	2	7.41
Tutorial	5	18.52
Date / frame conditions	3	11.11
Other	2	7.41
Video tutorials	11	40.74
Lacking need	8	29.63
Not known	2	7.41
Other	2	7.41

Note. Reported are only categories with $n > 1$; n = number of transcripts in which the use of a strategy was reported at least once; % = percentage of overall transcripts in which the use of the strategy at least once.

Curriculum Vitae

Name	Franziska Dorothea Wehner (née Koch)
Date of birth:	06.09.1990
Place of birth:	Stuttgart, Germany
Family status:	Married

Education and scientific career

2009	Abitur at the Königin-Katharina-Stift Stuttgart, Stuttgart, Germany
2009 - 2012	Study of Psychology (B. Sc.) at Heidelberg University, Germany
2012 - 2014	Study of Psychology (M. Sc.) at Heidelberg University, Germany
since 2014	Research associate at the Forschungsgruppe Arbeits- und Ingenieurpsychologie, Institute of Psychology, Technische Universität Darmstadt, Germany

Grants and awards

2015	Research award (as part of the gender equality action plan) of the Department of Human Sciences, Technische Universität Darmstadt
2015	Women's advancement funds of the Department of Human Sciences, Technische Universität Darmstadt
2018	Women's advancement funds of the Department of Human Sciences, Technische Universität Darmstadt

Publications

Wehner, F. D. (2018, June), *Video tutorials in mathematics education for engineering students.* Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah.

Dirsch-Weigand, A., Pinkelman, R., Wehner, F. D., Vogt, J., & Hampe, M. (2018). Picking low hanging fruits – Integrating interdisciplinary learning in traditional engineering curricula by interdisciplinary project courses. In M. E. Auer & K.-S. Kim (Eds.), *Engineering education for a smart society. World Engineering Education Forum & Global Engineering Deans Council 2016* (Vol. 627, pp. 97-106). doi: 10.1007/978-3-319-60937-9_8

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Koch, F. D., & Vogt, J. (2015). Psychology in an interdisciplinary setting: A large-scale project to improve university teaching. *Psychology Learning & Teaching*, *14*(2), 158-168. doi: 10.1177/1475725715590707