Skill or Will?

Comprehensive Conceptualization of Technology-Enhanced Teaching and its Relation to Teachers' Professional Knowledge and Motivation

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SUMMARY

Politicians and researchers claim that educational technologies offer great potential to enhance teaching quality. However, recent research demonstrated that even when teachers have the relevant technical infrastructure available, they rarely use the potential of technologies for teaching (Fraillon, Ainley, Schulz, Friedman, & Duckworth, 2019). Therefore, researchers investigate and discuss teachers' professional competence as a central boundary condition for their use of technologies in the classroom (e.g., Scherer, Siddiq, & Tondeur, 2019). However, existing literature has two major weaknesses: First, there is no comprehensive conceptualization of technology integration in the classroom as previous research mostly used survey studies and therefore examined rather distal indicators of technology use. Second, even though there are well-defined models of teachers' generic professional competencies, there is no comprehensive framework of professional competencies for technology-enhanced teaching.

Considering these issues, the present dissertation targeted four aims: first, to provide and apply a reliable and *comprehensive conceptualization of technology integration* in classrooms; second, to augment the existing body of research with elaborated methodological approaches to enable fine-grained insights into how teachers currently integrate technologies into their teaching; third, to provide a *comprehensive framework of teachers' technology-related professional competencies* by establishing a link between previous research on generic professional competencies of teachers and competencies the teachers need for technology-enhanced teaching; and fourth, to disentangle the relative role of the different components of teachers' professional knowledge and motivation in a comprehensive way. To this end, I conducted, together with colleagues, three empirical studies in which we investigated the relation of teachers' professional competencies and their technology-enhanced teaching.

First, in a quasi-experimental approach I studied the relations of teachers' competencies and the quality of technology-enhanced lesson plans (N = 94 German teachers varying in their relative expertise; Backfisch et al., 2020a). This approach allowed me to establish a comprehensive conceptualization of the quality of technology-enhanced teaching with clearly defined indicators. Furthermore, I investigated the relative role of teachers' skill and will for the quality of technology-enhanced teaching. The analyses revealed that teachers' perceived utility value regarding educational technologies, but not their professional knowledge played a

crucial role for designing technology-enhanced mathematics instruction. Based on these findings, two major questions remained open which were addressed in the subsequent studies. First, it was still unclear how exactly the utility value and technology integration relate to each other, for example, which contextual aspects influence this relationship. Second, the question arose whether this relationship of teacher motivation and technology integration remains stable across contexts.

Therefore, in a second study, I further examined the relative role of different components of teacher motivation and quantity and quality of technology integration with an experience sampling approach (N = 18 German teachers teaching in technology-rich classrooms). The teachers kept a teacher diary over six weeks. This approach allowed me, first, to apply the comprehensive conceptualization and indicators of technology-enhanced teaching quality to other subject domains and, second, to analyze the relation of teacher motivation and technology integration in a highly situated manner. By using a mixed method approach it became apparent that teachers' utility value determined the quality of technology integration. Additionally, qualitative analyses showed that instructional contexts (e.g., teaching materials used) affected the overall quality of technology integration. In a third study, I further analyzed the relations between teachers' self-efficacy, utility value, and technology integration with a survey among teachers (N = 524) teaching in a governmental initiative for full technical infrastructure in a Norwegian municipality. This study design allowed me to examine the relations of teachers' self-efficacy on their technology integration in a fine-grained manner and to investigate the stability of the previous findings in a different educational system. Based on latent structural equation modelling, an integrated model was suggested which encompassed both (a) direct and indirect relations of self-efficacy and technology integration and (b) direct relations of utility value and technology integration. Therefore, utility value was found to be a crucial enabler for teachers' technology integration across studies and contexts.

Overall, the present dissertation contributes to the scarce theoretical and methodological background by offering, first, a comprehensive conceptualization of teachers' technology integration. This conceptualization is based on indicators of teaching quality and evidence gained from research of effective learning through technology use. Second, the present dissertation provides a conceptualization of teachers' professional competencies for technology-enhanced teaching, which highlights the found importance of teacher motivation for effective technology use. Additionally, the findings can be applied within teacher education to support and evaluate the quality of technology-enhanced teaching and associated professional competencies. Therefore, the present dissertation adds an important constituent to move the educational system one step further in the digitized 21st century.

ZUSAMMENFASSUNG

Politik und Forschung betonen, dass digitale Medien ein großes Potenzial zur Verbesserung von Unterricht bieten. Neuere Studien haben jedoch gezeigt, dass Lehrpersonen, selbst wenn sie über die entsprechende technische Infrastruktur verfügen, das Potenzial von digitalen Medien für den Unterricht nur selten nutzen (Fraillon, Ainley, Schulz, Friedman, & Duckworth, 2019). Daher werden innerhalb der Forschung aktuell die professionellen Kompetenzen von Lehrpersonen als zentrale Determinante für den Einsatz digitaler Medien im Unterricht diskutiert (z.B. Scherer et al., 2019). Die bereits existierende Literatur weist jedoch zwei wesentliche Schwächen auf: Erstens gibt es keine umfassende Konzeptualisierung davon, wie digitale Medien im Unterricht genutzt werden sollten. Bisherige Forschung greift zumeist auf Fragebogenstudien zurück und untersucht daher eher distale Indikatoren der Nutzung digitaler Medien im Unterricht. Zweitens gibt es zwar gut definierte Modelle der überfachlichen professionellen Kompetenzen von Lehrpersonen, aber kein umfassendes Rahmenmodell professioneller Kompetenzen für das Unterrichten mit digitalen Medien.

Unter Berücksichtigung dieser Problematik erfüllte die vorliegende Dissertation vier Ziele: Erstens, wurde eine zuverlässige und umfassende Konzeptualisierung der Nutzung digitaler Medien im Unterricht entwickelt und eingesetzt. Zweitens, wurde die bisherige Forschung durch elaborierte methodische Ansätze erweitert. Dies ermöglichte differenzierte Einblicke in die Art und Weise, wie Lehrpersonen gegenwärtig digitale Medien in ihrem Unterricht einsetzen. Drittens, wurde ein umfassendes Modell für die professionellen Kompetenzen von Lehrpersonen für das Unterrichten mit digitalen Medien entwickelt. Dieses Modell stellte eine Verbindung zwischen früheren Forschungsarbeiten zu den allgemeinen professionellen Kompetenzen und den Kompetenzen her, die Lehrpersonen für einen Unterricht mit digitalen Medien benötigen. Viertens, wurde die relative Rolle der verschiedenen Komponenten des professionellen Wissens und der Motivation von Lehrpersonen untersucht. Zur Erfüllung dieser Ziele habe ich, zusammen mit Kolleginnen und Kollegen, drei empirische Studien durchgeführt, in denen wir die Beziehung zwischen den professionellen Kompetenzen von Lehrpersonen und ihrem Unterricht mit digitalen Medien untersucht haben.

Zunächst untersuchte ich in einer quasi-experimentellen Studie das Verhältnis von Kompetenzen und der Qualität von Unterrichtsplänen, in denen digitale Medien genutzt wurden (N = 94 deutsche Lehrpersonen mit unterschiedlicher Expertise; Backfisch et al., 2020a). Dieser Ansatz ermöglichte es mir, eine umfassende Konzeptualisierung der Qualität des Unterrichts mit digitalen Medien auf Basis klar definierter Indikatoren anzufertigen. Darüber hinaus untersuchte ich die relative Rolle des Wissens und der Motivation der Lehrpersonen für die Qualität des technologiegestützten Unterrichts. Die Analysen ergaben, dass die wahrgenommene Valenz von Lehrpersonen bezüglich digitaler Medien, nicht aber ihr professionelles Wissen, eine entscheidende Rolle bei der Gestaltung einer technologiegestützten Mathematikunterrichtsstunde spielte. Auf der Grundlage dieser Ergebnisse blieben zwei Hauptfragen offen, die in den nachfolgenden Studien behandelt wurden. Zum einen blieb die Frage offen, wie genau sich die Valenz und die Nutzung digitaler Medien im Unterricht zueinander verhalten und wie beispielsweise kontextuelle Aspekte dieses Verhältnis beeinflussen. Zum anderen wurde die Frage aufgeworfen, ob dieses Verhältnis von Motivation und Nutzung digitaler Medien über die Kontexte hinweg stabil bleibt.

Daher habe ich in einer zweiten Studie die relative Rolle verschiedener Komponenten der Motivation und der Quantität und Qualität der Nutzung digitaler Medien mit einem Experience Sampling Ansatz weiter untersucht (N = 18 deutsche Lehrpersonen, die in gut mit digitalen Medien ausgestatteten Schulen unterrichten). Hierbei führten die Lehrpersonen über 6 Wochen hinweg ein Unterrichtstagebuch. Dieser Ansatz ermöglichte es mir, erstens, die umfassende Konzeptualisierung und die Indikatoren für die Unterrichtsqualität mit digitalen Medien auf andere Fachbereiche anzuwenden und, zweitens, das Verhältnis von Motivation und Nutzung digitaler Medien zu analysieren. Unter Verwendung eines Mixed Model Ansatzes zeigte sich, dass die Valenz der Lehrpersonen die Qualität der Nutzung digitaler Medien im Unterricht bestimmte. Zusätzlich zeigten qualitative Analysen, dass Unterrichtskontexte (z.B. verwendete Lehrmaterialien) die Qualität der Nutzung digitaler Medien im Unterricht beeinflussten.

In einer dritten Studie untersuchte ich die Beziehungen zwischen der Selbstwirksamkeit und der Valenz bezüglich digitaler Medien von Lehrpersonen und der Nutzung digitaler Medien im Unterricht. Dazu analysierte ich die Daten einer Fragebogenstudie unter Lehrpersonen (N = 524), die in einer Initiative für eine vollständige technische Ausstattung in einer norwegischen Kommune unterrichteten. Dieses Studiendesign ermöglichte es, die Beziehungen zwischen der Motivation von Lehrpersonen und ihrer Nutzung digitaler Medien im Unterricht differenziert zu untersuchen und die Stabilität der bisherigen Ergebnisse in einem anderen Bildungssystem zu überprüfen. Auf der Grundlage einer latenten Strukturgleichungsmodellierung wurde ein integriertes Modell vorgeschlagen, das sowohl direkte als auch indirekte Zusammenhänge der Selbstwirksamkeit und der Nutzung digitaler Medien im Unterricht, sowie direkte

Zusammenhänge der Valenz und der Nutzung digitaler Medien im Unterricht umfasste. Somit spielte die wahrgenommene Valenz digitaler Medien von Lehrpersonen über die Kontexte hinweg eine wichtige Rolle für die Nutzung digitaler Medien im Unterricht.

Insgesamt leistet die vorliegende Dissertation einen Beitrag zu der bisher geringen theoretischen und methodischen Grundlage zum Zusammenhang von professionellen Kompetenzen von Lehrpersonen und deren Unterricht mit digitalen Medien. Dazu wurde eine umfassende Konzeptualisierung der Nutzung digitaler Medien im Unterricht entwickelt, die auf Indikatoren der Unterrichtsqualität und des technologiegestützten Lernens basiert. Zudem wurde eine Konzeptualisierung der professionellen Kompetenzen von Lehrpersonen für den technologieunterstützten Unterricht ausgearbeitet, die die festgestellte Bedeutung der Motivation für die effektive Nutzung digitaler Medien hervorhebt. Die Ergebnisse können darüber hinaus innerhalb der Lehrerbildung angewendet werden, um die Qualität des Unterrichts mit digitalen Medien und der damit verbundenen professionellen Kompetenzen zu unterstützen und zu bewerten. Daher trägt die vorliegende Dissertation einen wichtigen Teil dazu bei, das Bildungssystem im digitalisierten 21. Jahrhundert einen Schritt voran zu bringen.

1 INTRODUCTION

1.1 Problem Statement

Digital transformation takes place in every aspect of today’s society. As a consequence, not only have macro economical and macro societal processes undergone digital transformation, but also individual everyday activities have changed. For example, digital tools enable new global communication such as (a)synchronous digital communication of people who are in different parts of the world. Especially in the current situation of a worldwide pandemic, this became crucial to enable both the persistence of global economic relationships and the home schooling of students. However, the increasing digitization also involves obstacles and challenges such as with regard to handling and filtering the enormous information variety provided by the worldwide web. This challenge is a considerable one both for teachers, as they have to find adequate teaching material, and for their students, as they have to find appropriate information for the given homework. To face these problems, digital literacy has become an essential competence in the 21st century.

Therefore, predominantly political statements encourage the use of technologies in schools in order to improve students' digital literacy to actively participate in the 21st century (Fraillon et al., 2019; KMK, 2016; MOK, 2006; NETP U.S. Department of Education, 2020; OECD, 2015). This digital literacy encompasses not only the competent use of technologies for learning-related purposes (e.g., conducting web queries), but also the awareness of potential risks (e.g., ability to identify trustworthy sources within web queries). Furthermore, educational technologies are attributed a great potential to contribute to the quality of teaching and, in return, student learning (Chauhan, 2017; Mayer, 2019; Zhu & Urhahne, 2018). For example, the German Ministers of Education defined in their strategy paper in 2016 that teachers should use technologies to enrich their pedagogical teaching practices and simultaneously foster students’ digital literacy in every subject and across all grade levels (KMK, 2016). Norway even established the development of students’ digital literacy as a basic skill and as one of the core objectives of schooling since 2006 (MOK, 2006). Therefore, since then, technologies have been expected to be used across subjects and across all grade levels. In sum, teaching with technologies should not only enhance students’ learning, but also enable them to play an active role in a digitized 21st century society.

However, in order to implement technology-enhanced teaching that meets these high expectations, two main issues must be addressed, which have not been adequately investigated in existing research so far:

First, a comprehensive evidence-based *conceptualization of what constitutes good technology-enhanced teaching* is yet missing. Therefore, distinct indicators for successful technology integration are not defined such as fostering students' cognitive engagement in a task through technology use. Existing research mostly used survey studies and therefore examined distal indicators of technology integration such as the frequency of its use. Therefore, even though there are generic frameworks of teaching quality and an extensive body of research on technology-enhanced learning, these two lines of research are mostly independent of each other and have not impacted the research on technology-enhanced teaching so far. In particular, indicators for teaching quality (e.g., cognitive activation of the students as one of the generic dimensions of teaching quality; Praetorius, Klieme, Herbert, & Pinger, 2018) and evidence from research on technology-enhanced learning (e.g., multimedia research; Li, Antonenko, & Wang, 2019; Moreno & Mayer, 2007; Renkl & Scheiter, 2017) are not yet applied to analyze technology-enhanced teaching quality. This potentially leads to a lack of comprehensive implications for educational practice and policy makers.

Second, a comprehensive evidence-based conceptualization of the *professional competencies* the teachers need for teaching with technologies is missing. Previous research has not systematically examined the relationships between different aspects of teachers' professional competence and their technological integration. Professional competence is generally defined as the *professional knowledge* and *motivational beliefs* that form the basis for mastering specific professional situations (see Epstein & Hundert, 2002; Kane, 1992; Kunter et al., 2013; Lauermann & König, 2016). However, existing frameworks and empirical investigations mainly focused on describing the relations between only one of the various aspects of professional competence and the use of technology. Moreover, studies often used teachers' self-assessed professional knowledge and their self-reported use of technology during teaching (e.g., Fraillon et al., 2019; Scherer, Tondeur, & Siddiq, 2017) or only investigated teachers' motivation and their acceptance of technologies (e.g., Scherer & Teo, 2019). Only recently, research also investigated relations between teachers' motivation and their use of technologies in the classroom (e.g., Taimalu & Luik, 2019; Vongkulluksn, Xie, & Bowman, 2018). However, there are no comprehensive studies of the relationships between the various aspects of professional competence and the use of technology in teaching.

1.2 Aims and Objectives of the Dissertation

In line with the identified issues of the existing research, four aims were addressed in the present dissertation. The first aim of the present dissertation was to provide and apply a comprehensive and reliable *conceptualization of technology integration* that is grounded in empirical research on teaching quality and evidence from technology-enhanced learning. To achieve this aim, existing research on teaching quality and technology-enhanced learning (TEL) was examined in order to identify potential indicators for high-quality technology integration.

The second aim was to augment the existing body of research with *elaborated methodological approaches* to enable fine-grained insights into *how* teachers currently integrate technologies into their teaching. To reach this goal, different empirical methodological approaches, such as quasi-experimental and experience sampling designs, and qualitative content analyses were applied to identify the different types and methods of technology integration during teaching. This allowed for a more detailed investigation of technology integration than existing quantitative survey studies—previous research mostly relied on distal indicators of technology integration such as frequency of technology use, resulting in bird's-eye investigations that made it hard to derive theoretical and practical implications regarding the quality of technology integration.

The third aim was to *establish a link* between previous research on general professional competencies of teachers and competencies the teachers need for technology-enhanced teaching. Within existing literature, boundary conditions of teachers including their professional knowledge and motivation are predominantly discussed independently of what is known about the relationship of teachers' professional competencies and their teaching behavior. For that reason, in the present dissertation project, existing generic models of teachers' professional competencies were transferred and empirically tested within the field of technology-enhanced teaching.

The fourth aim was to disentangle the *relative role* of the different components of teachers' professional knowledge and motivation in a comprehensive way. As previous research described teachers' boundary conditions and various components of competence independently from each other, the relative contributions of these components were not known. Therefore, in the present dissertation, study designs were applied that allowed for investigating different components simultaneously to determine relative contributions and potential relations between competencies and use of technologies during teaching. Additionally, the empirical studies were conducted in different contexts including regular schools and schools with extensive availability of technologies and educational systems, namely Germany and Norway. This procedure allowed for reliable and widely adaptable insights into the relative role of teachers' professional knowledge and different facets of motivation on their technology integration.

2 TEACHING WITH TECHNOLOGY

Technology is commonly defined as a *systematic treatment* meaning that something is treated in an organized and clear sequence. Nowadays, both the application of scientific knowledge for practical purposes and the equipment that is developed from the application of scientific knowledge are summarized under the term technology (LEXICO, 2019). Therefore, in general, technologies encompass all objects that are man-made such as pens and blackboards. More recently, however, the term technology refers predominantly to digital technologies that include hardware and software applications (e.g., computers, laptops, word processing software). When these digital technologies are used in the classroom, they are generally termed as educational technologies. Educational technologies refer to different hardware (e.g., interactive whiteboards, laptops, tablet computers; see e.g., Beauchamp, Burden, & Abbinett, 2015) or software applications (e.g., generative and domain-specific online applications; see e.g., Krauskopf, Zahn, & Hesse, 2012).

Technology-enhanced teaching (TET) typically refers to whether and how teachers use educational technologies during classroom instruction to implement specific teaching strategies and foster their students' learning processes (Danniels, Pyle, & DeLuca, 2020; Dukuzumuremyi & Siklander, 2018; Näykki, & Järvelä, 2008; Paratore, O'Brien, Jimenez, Salinas, & Ly, 2016). Historically, technologies were mainly attributed the potential to transmit and deliver information from the teachers to their students. Therefore, teachers predominantly used visualizations such as flow charts to illustrate a distinct process. In traditional classrooms, teachers could draw the chart on the blackboard. From the 1960s, teachers could alternatively use prepared overhead projector slides to present the chart. Nowadays, teachers could use a digital tool that is connected to a laser projector to present the chart. On the contrary, Jonassen (2005) postulated the term *technologies as cognitive tools* which encompasses the use of technologies as a deliberate method to foster distinct teaching and learning processes. Therefore, technologies should be used not only to deliver information but also to support students' cognitive processes during learning. The author highlighted that teaching and learning is a holistic process which will not change only through the use of another technology (e.g., present the chart in a digitized way). However, if the technologies are used as cognitive tools, they enable new teaching and learning processes which foster students' learning. For example, instead of presenting a chart, teachers could provide virtual simulation to students that visualizes and demonstrates each step of a distinct process in detail (De Jong, Linn, & Zacharia, 2013).

In line with the debate on meaningful technology use during teaching, recently, tablet computers have been discussed as having great potential for promoting teaching and learning processes. Since the introduction of the first iPad in 2010 by Apple and following tablet products by further companies (e.g., DELL, Samsung), tablets have been used in schools because of the special affordances these mobile technologies offer for learning. Tablets combine multiple features in one device while they are portable and flexible. In addition, there is an increasing number of generative applications which foster learning across domains, including apps for formative assessment such as Socrative or Kahoot. Additionally, there are domain-specific software applications including mathematical simulation software such as GeoGebra. Both types of applications allow an easy customization of tablets to students' needs (Beauchamp et al., 2015; Hassler, Major, & Hennessy, 2016; Major, Hassler, & Hennessy, 2017; Scheiter, 2017). Therefore, in the present dissertation, the empirical investigations focus on the use of tablets for teaching and learning processes.

2.1 Availability of Technology in Education

When discussing how teachers integrate technologies into their classrooms, it is important to first consider whether they have access to the particular infrastructure. This concerns the question of how many technologies are available in their schools such as the amount of accessible technical devices as well as the infrastructural equipment. However, this availability is known to differ largely across different educational systems and countries.

The largest study that investigated the availability of technologies in schools is the International Computer and Information Literacy Study (ICILS), which was conducted in 2013 and 2018, respectively (Fraillon et al., 2019). In ICILS 2013, 35,000 teachers and their 60,000 8th-grade students from 21 countries, including Germany and Norway, participated; in ICILS 2018, 26,000 teachers and their 46,000 8th-grade students from 14 countries including Germany, but not Norway participated. The studies showed reasonable differences regarding the availability of technical infrastructure across countries. In 2013, the average number of pupils per computer in the European Union was 11.6:1. That proportion indicates that approximately 12 pupils have to share one computer. Germany was close to this average, while Scandinavian countries like Norway in particular had more technical equipment (proportion 2.4:1). In 2018, the proportion improved slightly in Germany (proportion 10:1); nonetheless, the proportion was still far worse than in other countries such as the Scandinavian countries (Denmark 5:1, Finland 3:1). However, if one considers only the number of tablet computers, the proportion in Germany was better than the international average, with 41.1 pupils per tablet computer in Germany compared to 54.5:1 internationally. In addition to the amount of technical devices available at schools, ICILS investigated how often the approach *bring your own device* (BYOD) was implemented. BYOD indicates that pupils use their private devices such as their smartphones, tablets, and laptops during the lessons. Notably, the BYOD approach is not very common in German schools as only 15% of students reported using BYOD; in contrast, BYOD is daily practice in other countries such as the Scandinavian countries (e.g., 90% of students reported using BYOD in Denmark). At least as important for technology-enhanced teaching as the devices themselves is the technical infrastructure, such as internet access, to be able to use them in a meaningful way. However, Germany has a deficit in technical infrastructure such as the availability of WiFi for pupils and teachers (schools with WiFi in Germany: 26%; in comparison, Denmark: 100%, Finland: 91%, international average: 65%). Moreover, basic software-related infrastructure to teach with technologies such as e-mail addresses for every student is available for only 30% of German students, but for almost every student in Scandinavian countries (Denmark 91%, Finland 93%; international average: 55%). The same picture evolves when investigating the availability of learning management systems (LMS). Only almost half of German schools (45%) have LMS available, whereas almost all Scandinavian schools have LMS (Denmark: 83%, Finland: 97%; international average: 65%). Furthermore, in Germany the provided infrastructure is often troublesome as systematic technical support is rare and teachers themselves are often responsible for the proper functioning of the infrastructure with only little professional support, for example, from the regional government (Eickelmann, Gerick, Labusch, & Vennemann, 2019).

To address the problematic technical infrastructure, there is an increasing number of governmental initiatives and foundations across countries that fund the digital infrastructure of schools (e.g., ‘Digitalpakt’ in Germany provides 5 billion € for digital infrastructure in schools; Bill & Melinda Gates foundation awards special grants to enhance the technological infrastructure in schools in the U.S.). Besides initiatives that are aimed at improving the technical infrastructure in general (e.g., WiFi access, LMS), there are initiatives that exclusively support one-to-one equipment. Within these one-to-one initiatives, typically both teachers and students are provided with one digital device each, which can be used individually on a daily basis (Beauchamp et al., 2015; Fleischer, 2012; Keane & Keane, 2019; Liu & Milrad, 2010). In Germany, technologies used for teaching and learning are mostly provided by the schools. Accordingly, these initiatives are often implemented in distinct smaller districts such as specific cities or municipalities. For example, within the *tabletBW* -initiative in the German federal state of Baden-Württemberg (http://tablet-tuebingen.de), 18 academic track schools (i.e., Gymnasien) received money to equip their students and teachers of 7th-grade classes (64 classes in total; age of students: 12-13 years) with tablet computers. Another example would be the initiative in Asker, Norway, near Oslo. Within this initiative, all primary schools (Grades 1-7; age of students: 6-13 years) and lower secondary schools (Grades 8-10; age of students: 13-16 years) in Asker were equipped with technological hardware and infrastructure. All students and teachers in Grades 1-4 received tablet computers, whereas all students and teachers in Grades 5-10 received laptops. Within the initiative, all teachers teaching in these schools participated in a professional development program, and they were asked to teach with technologies in their daily classroom practice.

If one is interested in studying how technologies are integrated in schools, these initiatives provide a unique research environment in contrast to survey studies. Survey studies such as ICILS that investigated the current status of technologies in schools across countries showed that, overall, there is still little technological availability. At the same time, however, the studies reported high variability across countries and also within countries (e.g., differences in availability of technologies between urban and rural schools ranged in ICILS 2018 from no difference in Italy to a ratio difference of 7:1 in the Republic of Korea; Fraillon et al., 2019). Furthermore, peculiar findings can be derived from these large-scale studies, such as the fact that in the Czech Republic it was found that the availability of technology was low but that the existing technology was nevertheless frequently used (Fraillon et al., 2019). In sum, there might be too many confounds in survey studies to examine in detail how teachers integrate technologies into their teaching. In contrast, governmental initiatives such as tabletBW and the initiative in Asker provide a technology-rich research context for investigating boundary conditions for technology integration.[1] Here, necessary conditions for technology integration,

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[1] *Note*: The research within these initiatives was ongoing during the completion of the present dissertation.

namely its availability, are given, thereby allowing investigation of how and when technologies are integrated.

2.2 Quantity of Technology Integration

The use of technology in schools and thus *technology integration* in the classroom is promoted in the political and scientific debate. Recently, there have been repeated calls for technologies to be integrated in a meaningful and efficient way (Fraillon et al., 2019; KMK, 2016; MOK, 2006; OECD, 2015). However, a clear and comprehensive definition of what this efficient technology integration should look like is missing. Therefore, in the present section, first, indicators for the quantity of technology integration are presented to lead to, second, a newly developed concept of the *quality of technology integration* (see Chapter 2.3).

In previous research, technology integration was mostly conceptualized on a quantitative level. This quantity of technology integration is measured, for example, by simply asking teachers and/or their students to report how often a particular technology has been used in class (e.g., Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014). These quantity indicators provide a valuable overview of the general level of technology use in schools in an efficient way. However, self-reports of the frequency of technology use should be treated with caution, as they could be prone to errors due to retrospective bias. This bias might for instance result from teachers having to report retrospectively on their average technology use over long periods of time with potentially very different lessons and instructional contexts. Therefore, self-reported frequency of technology use can only serve as a proxy for established technology integration.

For instance, in ICILS 2018 teachers were asked to rate how often they used technologies when teaching the nominated reference class[2] during the ongoing school year. To specify their judgement, the teachers rated the frequency of technology use based on 16 different digital tools ("never," "in some lessons," "in most lessons," or "in every, or almost every lesson"; Fraillon et al., 2019). The different digital tools reflected different types of technology use such as to present information or to deliver information with digital text books. On international average, less than half of the teachers reported using the different digital tools in at least most of the

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[2] Teachers had to choose one reference class which they should keep in mind when answering the question. This reference class should be the first 8th-grade class they taught on Tuesdays (or the next day of the week if they did not teach 8th grade on Tuesday).

lessons. When combining the two highest frequency categories (i.e., “in most lessons” and “in every, or almost every lesson”), differences in the percentages of teachers who reported to use the various digital tools were apparent. The most frequently used digital tools were presentation tools (43%) and digital content linked to textbooks (32%). Accordingly, 64% of teachers reported to use technologies in most lessons, almost every, or every lesson to present information through direct class instruction, however, less teachers reported to use technologies for student-centered teaching approaches (e.g., inquiry learning with technologies: 40% of teachers). A comparison of the data of Germany and Scandinavian countries based on ICILS 2013 and ICILS 2018 showed that across measurement points and types of technology usage, German teachers used the technologies less often than teachers from the Scandinavian countries. However, the tendencies regarding which types of technology were used most often by teachers in a country were the same across countries. Teachers used technologies most often to present information through direct class instruction, whereas the use for more complex teaching approaches such as inquiry learning was lower. The comparison of the data of 2013 and 2018 additionally showed an increase in the different types of usages between the two measurement points (see Table 1). Secondary analyses within the German *Länderindikator 2017* of the ICILS data showed that German teachers were often not aware of the opportunities of technologies for students’ content-specific learning; rather they aimed to ensure that students acquired technological knowledge, such as skills in handling technologies (Lorenz et al., 2017).

In contrast to the high expectations regarding technology-enhanced teaching to enhance students’ domain-specific and technology-related learning, previous research showed only little relation between quantitative aspects of teachers’ technology integration and students’ learning gains (Fraillon et al., 2019; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). In ICILS 2018 researchers even found a negative correlation of frequency of technology integration and students’ digital literacy in Germany (Fraillon et al., 2019). However, one has to note that the quantitative indicators of technology integration in survey studies are rather coarse-grained and can provide a summary from a bird’s-eye view only. Therefore, they cannot uncover deeper qualitative aspects on *how* technologies are integrated, which are likely to be crucial for the effectiveness of technology integration (e.g., technology use that improves the quality of teaching; OECD, 2015).

Table 1

Teachers' Use of Technologies based on ICILS 2013 (Fraillon et al., 2014) and ICILS 2018 (Fraillon et al., 2019)

	Use of presentation tools[a]	Use of digital content linked to textbooks[b]	Present information through direct class instruction	Support of inquiry learning
ICILS 2013				
Germany	10 (1.4)	NA	13 (1.3)	4 (0.7)
Denmark	31 (2.8)	NA	41 (2.5)	15 (1.7)
Norway	19 (1.5)	NA	33 (2.1)	5 (0.9)
ICILS 2018				
Germany	21 (1.6)	6 (0.7)	48 (1.7)	22 (1.6)
Denmark	64 (2.0)	18 (1.3)	77 (2.3)	59 (1.8)
Finland	27 (1.0)	32 (1.3)	70 (1.3)	33 (1.3)

Note. Numbers represent percentages of teachers who reported using technologies in at least half of the lessons for the distinct task (standard errors in parentheses). [a] In ICILS 2013 this was only assessed together with the use of word processors. [b] In ICILS 2013 this item was not assessed.

2.3 Quality of Technology Integration

The quality of technology integration focuses on technology use as a cognitive tool which pursues distinct teaching and learning objectives (Jonassen, 2005). Thus, models of educational technologies and teaching quality are synthesized to provide a comprehensive conceptualization of what constitutes effective technology integration in the classroom. Regarding teaching processes, technologies can, for example, make the teaching smoother through learning management systems (e.g., Moodle, ILIAS) and their easy provision of learning material. This technology-enhanced learning material can improve students' distinct learning processes such as supporting the acquisition of conceptual knowledge through virtual simulations, or facilitating students' metacognitive processes and self-regulation skills by providing just-in-time feedback on students' learning progress (Aleven, Roll, McLaren, & Koedinger, 2016; Olympiou, Zacharias, & deJong, 2013).

To examine the quality of technology integration, technology use can be operationalized on either the *product* or *process* level of technology integration (Hamilton, Rosenberg, & Akcaoglu, 2016). First, on the product level, *technology exploitation* can be examined. In particular, technology exploitation refers to how teaching methods are changed through technology use such as if they are designed more innovatively and if diverse features of the technologies are used. Therefore, technology exploitation focuses only on the kind of technology use during teaching. Technology exploitation does not refer to the potential impact of technology integration on teaching and learning processes. Thus, second, on the process level, *technology-enhanced teaching quality* can be examined. This conceptualization of quality, which was developed in this dissertation, focuses on how technology-enhanced methods impact teaching and learning processes.

2.3.1 Technology exploitation

The degree of *technology exploitation* refers to how the products of teaching such as the teaching methods changed through the use of technologies. The use of technologies includes use of their distinct hardware (e.g., laptop, laser projector) as well as software (e.g., word processing program, presentation tool). The use of these technologies potentially leads to powerful learning environments, which enable and support learning processes (Gerjets & Hesse, 2004). It is important to note that the technologies differ in their offered potential based on the distinct characteristics of their hard- and software. For example, a mere PDF document read on a tablet does not have any advantage to reading a book, whereas processing an interactive reading task with individual feedback has a high positive impact on learning (see Swart, Nielen, & Sikkema-de Jong, 2019, for meta-analytic evidence).

Models that conceptualize the level of technology exploitation are often applied by practitioners and increasingly by researchers to categorize and describe different levels of technology use during teaching (Hamilton et al., 2016). The most popular models for conceptualizing the different levels of technology exploitation in a hierarchical order are the SAMR model (acronym for Substitution, Augmentation, Modification, Redefinition by Puentedura, 2006) and the RAT model (acronym for Replacement, Amplification, Transformation by Hughes, Thomas, & Scharber, 2006).

The SAMR model encompasses four hierarchical levels (see Figure 1). The lowest level, substitution, describes a use of technologies that simply substitutes traditional media, such as distributing digital PDF files instead of hard copies. The second level, augmentation, describes technology usage that provides some functional improvement, such as a PDF document that has hyperlinks to additional information. The third level, modification, describes technology usage that leads to a significant redesign of the learning activity, for instance, if the students get automated individual feedback on their reading task. On the highest level, redefinition, technologies allow for the design of new tasks that were not doable without technologies. An example would be computer-based adaptivity of a text’s difficulty based on readers’ skills and learning pace.

Analogously, the RAT model (Hughes et al., 2006) describes at its lowest level, replacement, technologies that serve as a replacement of traditional methods with no additional benefit of using technologies. This first level is therefore equal to the substitution level of the SAMR model. The second level of the RAT model, amplification, encompasses the augmentation and modification levels of the SAMR model. Amplification consists of technology use that has an added benefit to traditional methods with a focus on increased efficiency and productivity. In particular, the tasks themselves remain the same, but can be accomplished faster and smoother through technology use. An example would be if teachers give individual feedback to their primary school students’ work via a learning management system, which automatically informs the students and their parents. The feedback with the learning management system is faster for the teachers and ensures that the parents can take a look. However, the method of teachers providing the feedback themselves remains the same. The highest level of the three hierarchical levels is transformation. Transformation implies technology integration that leads to new teaching methods and/or new subject matter, which would not be possible to teach without technology use. An example would be if the feedback to students is provided by an automated mechanism using artificial intelligence, which is also able to give advice and exercises adjusted to the individual student’s level. By using this automated feedback, it would be possible for students to receive immediate and more frequent feedback than teachers can give.

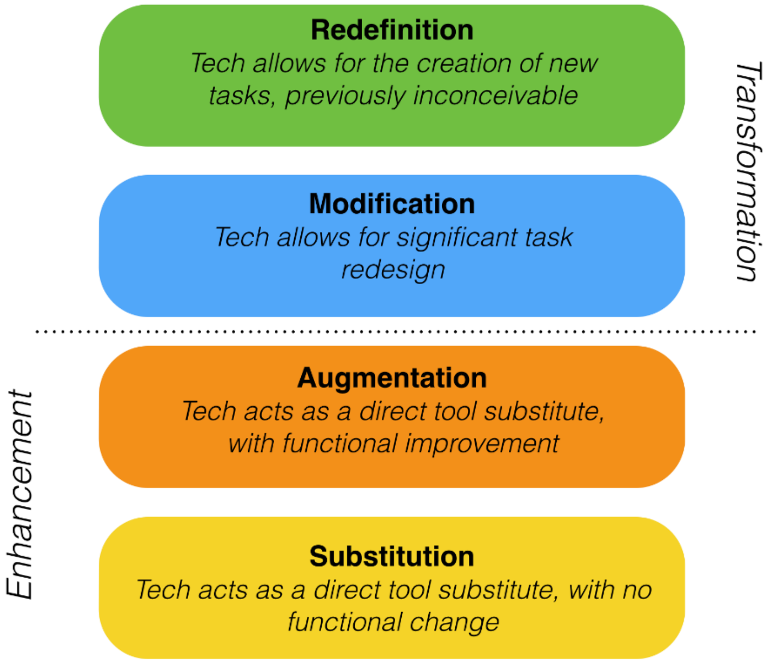


Figure 1. Figure of the SAMR Model by Puentedura (2006, http://hippasus.com/resources/tte/)

In sum, these models provide a conceptualization and categorization of the type of technology integration that is focused on the product level. In particular, these models help to describe how the teaching methods are designed differently through the use of technologies (Endberg, 2019; Hamilton et al., 2016). However, these models have two major weaknesses: First, the teaching and learning processes resulting from the different levels of technology integration are not examined; rather, the conceptualizations of technology integration capture only the surface level of integration, the teaching methods themselves. Second, these models do not consider the use of technology in the broader context of classroom teaching, but describe technology integration as a one-dimensional product. However, classroom teaching and learning is commonly conceptualized as a multifaceted and complex system. For example, one lesson might pursue learning objectives of varying complexity (e.g., learning of factual, procedural, and conceptual knowledge). Therefore, it might not be sufficient to analyze only the product level of technology integration, technology exploitation, to comprehensively depict the quality of technology integration.

2.3.2 Quality of technology-enhanced teaching (TET)

Against this background, an alternative conceptualization of the quality of technology integration that emphasizes teaching and learning processes was developed in the present dissertation. This developed conceptualization has its focus on how teaching and learning processes can be purposefully supported through the use of technologies. Therefore, the change of teaching methods is focused on not with regard to its innovativeness, but rather with regard to its impact on teaching and learning processes.

Recently, the first research syntheses of studies examining the impact of technologies on learning were conducted. For example, Hassler and colleagues (2016) reviewed studies (N = 23) that investigated the affordances of mobile devices such as tablet computers during teaching and learning. The studies showed a diverse picture when it comes to the learning gains through technology-enhanced teaching. Whereas many studies reported positive learning gains (e.g., learning with a tablet-based fraction game was superior to a traditional approach; Riconscente, 2013), there were also studies with neutral outcomes (e.g., using a tablet in mathematics for nine weeks was not superior to traditional teaching; Carr, 2012). Therefore, in order to understand the impact of technology-enhanced teaching (TET) on learning, it may be important to examine how technologies are integrated into teaching and learning processes. Hassler and colleagues concluded that this fine-grained view on TET should be made possible through elaborate research designs. This is in line with the conclusion of Chauhan (2017) who conducted a meta-analysis of 122 empirical quantitative studies that investigated the impact of technologies on learning of elementary school students. Most of the included studies applied pre-posttest designs with a technology-based intervention in between but without a control group (i.e., a group of participants who did not get an intervention). The overall mean effect size of these interventions was g = 0.54 (medium effect, Cohen, 2013). However, the individual effect sizes highly depended on contextual aspects such as the domain taught (i.e., using technologies in science had higher effect sizes, g = .72, than using them in social studies, g = .44), how the technologies were integrated (i.e., learning-oriented technology use was slightly more effective, g = .56, than general technology use, g = .48), and how long the intervention was (i.e., very short ≤ 1 week and very long > 6 months had large effects, while interventions in between had medium effect sizes). This meta-analysis provides valuable insights into the effectiveness of technology integration. Its results, however, should be treated with caution, as the included studies did not examine student learning in relation to a control group without technology use.

As an alternative approach, Stegmann (2020) integrated in his review 79 effect sizes from 10 meta-analyses to investigate to what extent technologies can improve teaching quality. To reach this goal, he categorized the use of technologies in the studies of the meta-analyses based on the ICAP framework (Chi, 2009). The ICAP framework classifies learning activities into four different levels: *P*assive (e.g., listening to a lecture), *A*ctive (e.g., taking notes during the lecture), *C*onstructive (e.g., writing a summary of the lecture), and *I*nteractive learning activities (e.g., discussing the contents of the lecture with fellow students). He showed that the effect sizes for studies that used technologies for constructive or interactive learning activities were higher than for passive and active activities (see e.g., Tamim et al., 2011, for similar findings based on a second-order meta-analysis). The meta-analysis by Stegmann (2020) suggests that indicators for generic teaching and learning quality also apply for effective technology-enhanced teaching.

In line with this suggestion, recently, models from research of learning processes such as the ICAP framework were also applied to evaluate technology-enhanced learning processes (e.g., Wekerle & Kollar, 2018). Wekerle and Kollar (2018) analyzed the type of technologies used within lesson plans of pre-service and in-service teachers (N = 270) with regard to the ICAP framework. However, in their preliminary analyses presented at a conference, the authors found no differences in the type of technologies used (i.e., the teachers used technology to a comparable extent for passive and constructive technology-enhanced teaching activities across expertise levels). This finding could be due to the fact that the ICAP framework was developed to analyze the quality of individual learning processes—the ICAP framework does not focus on teaching and learning processes within the broader and complex setting of learning within the classroom. Therefore, it might be the case that more comprehensive conceptualizations are needed to capture the quality of technology integration, such as generic models of teaching quality. This would also allow boundary conditions such as teachers’ professional competencies for TET to be investigated in a more pronounced way. Nonetheless, this more holistic perspective was not yet investigated within existing research on technology-enhanced teaching.

2.3.2.1 Generic teaching quality

In general, teaching quality is conceptualized as the performance and effectiveness of teaching with respect to various characteristics. The most prominent indicator for high teaching quality is students' learning. In this regard, students' learning not only involves students' domain-specific knowledge gains, but also encompasses their acquisition of domain-general knowledge, including digital literacy or meta-cognitive strategies such as self-regulated learning. Overall, the quality of teaching is conceptualized by a variety of models and theories such as the CLASS framework (Classrooms Assessment Scoring System; Brophy, 1999; Hamre & Pianta, 2007) or the COACTIV model (Professional Competence of Teachers Cognitively Activating Instruction; Baumert & Kunter, 2006; for an overview, see Eccles & Roeser, 2009; Pianta & Hamre, 2009). In contrast to models that are only focused on the learning processes themselves, such as the ICAP framework (Chi, 2009), models on teaching quality take a more holistic view on teaching and learning within the classroom. Within these models, the teachers are seen as facilitators for high teaching quality. Therefore, besides factors such as teachers' performance as socializers and motivators, teachers' performance in promoting student learning is the primary focus for assessing and evaluating teaching quality. This promotion of student learning also encompasses the quality of the learning activities such as the provided learning material by the teachers.

Predominantly within the German research context, the framework of three generic dimensions of teaching quality is discussed. This framework encompasses the following three aspects of teaching quality: cognitive activation, instructional support, and classroom management (Klieme, Schümer, & Knoll, 2001; see *The German Framework of Three Basic Dimensions* by Praetorius et al., 2018, for an overview). According to this framework, the quality of instruction and therefore teaching quality can vary both at the task-specific (i.e., cognitive activation and individual learning support) and task-general levels (i.e., classroom management; Baumert et al., 2010; Fauth, Decristan, Rieser, Klieme, & Büttner, 2014; Hugener et al., 2009; Kunter et al., 2013; Praetorius et al., 2018).

Cognitive activation refers to task-specific teaching strategies that trigger the cognitive engagement of students during learning. This engagement can be achieved, for example, by activating students' prior knowledge, or by enabling them to explore and explain relationships between different concepts. Therefore, these task-specific instructional strategies should lead to an in-depth processing of the content. To enable this in-depth processing, teachers also need to provide *individual learning support* such as feedback and adaptive support to scaffold students' task-specific learning processes. In addition, teachers have to establish and maintain a smooth and calm learning environment without disruptions and interpersonal conflicts. This task-general dimension of teaching quality is called *classroom management* as the teacher needs to be aware of all processes in the classroom. Researchers who investigated teaching quality based on these dimensions showed that even though teaching quality differs greatly between teachers, teaching quality, especially the level of cognitive activation, also varies within teachers across lessons (Fauth et al., 2019; Praetorius, Pauli, Reusser, Rakoczy, & Klieme, 2014; Turner & Meyer, 2000).

This framework of teaching quality has been applied across domains (e.g., mathematics: Kunter et al., 2013; reading: Lotz, 2014) and educational systems (see Praetorius et al., 2018, for an overview). In most cases, the empirical studies used self-reports of students and/or teachers (e.g., Fauth et al., 2014; Kunter & Baumert, 2006b), researchers' ratings of tasks provided to the students, or ratings of the classroom by trained observers. These observers rated the classroom either directly or from videotaped lessons (Hugener et al., 2009). Praetorius et al. (2018) reviewed all published instruments and identified the most often used subcategories to specify the judgement of the three dimensions of teaching quality. For cognitive activation, the authors identified three main subcategories: providing challenging tasks and questions, exploring and activating prior knowledge, and eliciting student thinking. For individual learning support, the authors identified four indicators, namely the level of teachers' differentiation and adaptive support, their pace of instruction, the level of constructive approach to errors, and students' support of experience social relatedness. Finally, for classroom management, the most common subcategories were a lack of disruptions and effective time use. One example of an empirical study is the investigation of 39 videotaped three-lesson mathematics units on the introduction to the Pythagorean Theorem by Hugener et al. (2009). The authors used observer ratings of the first lesson of the three-lesson unit. The observers based their ratings on Kunter and Baumert's (2006a) 'constructivist learning situation', and adopted the following five subcategories on a four-point Likert scale to specify the evaluation of the cognitive activation of the lessons with a satisfactory reliability (Cronbach's alpha = .80):

(a) the teacher initiated challenging activities at a high cognitive level,
(b) the teacher activated prior knowledge and existing concepts,
(c) the interaction between the teacher and the students supported conceptual change and conceptual expansion,
(d) the teacher encouraged the students to explain their ideas, concepts, and solutions, and
(e) constructivist understanding of learning: the teacher avoided solving problems by using procedures and solution methods by himself or herself (Hugener et al., 2009, p. 71).

Therefore, these developed categories provide a valuable conceptualization of different important aspects of teaching quality in mathematics. These categories can potentially serve as a basis for various other applications such as the analyses and evaluation of teaching in further domains. However, so far, the research on generic teaching quality has not been considered within (research on) TET.

2.3.2.2 Indicators for TET quality

To pursue the first aim of the present dissertation—the comprehensive conceptualization of technology integration during teaching—the indicators of teaching quality by Hugener et al. (2009) were transferred to technology-enhanced teaching (TET). In particular, the quality of technology integration was examined with regard to its impact on the abovementioned dimensions and indicators of teaching quality. For example, the present dissertation analyzed to what extent the use of technologies implies cognitively challenging activities for students or to what extent technologies were used to activate students’ prior knowledge. To specify the judgement, the developed conceptualization of the quality of TET within the present dissertation was informed by research on *technology-enhanced learning* (*TEL;* Prieto, Dlab, Gutiérrez, Abdulwahed, & Balid, 2011). Based on TEL research, one can conclude that technologies might predominantly enhance the teaching quality on the task-specific level (i.e., cognitive activation, instructional support). From the TEL research, especially the implementation of cognitively challenging learning tasks informed the developed conceptualization. A cognitively challenging task with technologies can for example be realized by using ubiquitous visualizations such as virtual simulations, or by implementing generative exercises such as the creation of explanation videos (De Jong, Linn, & Zacharia, 2013; Fiorella & Mayer, 2016). Therefore, models of technology-enhanced teaching quality can explain the degree to which technologies support different teaching and learning processes. That said, it was examined to what extent the distinct affordances of technologies were a meaningful part of the applied teaching methods and supported distinct learning processes. This conceptualization of the quality of technology integration referred to the *processes* of technology integration and thus to their potential impact on teaching and learning processes.

This conceptualization was first developed in the domain of mathematics and later broadened to capture domain-general aspects of TET quality. For the conceptualization of TET quality in mathematics, the five categories by Hugener et al. (2009) were adapted to fit to the demands of technology-enhanced lesson plans. First, the category ‘provision of cognitively challenging activities’ focuses on the complexity of the tasks provided by the teachers and therefore captures the extent to which students have to think about the tasks while processing them. This can be pursued, for example, through technology-based inquiry learning in virtual experiments (De Jong et al., 2013). This deep processing of the learning material potentially leads to sustainable learning (e.g., Kunter et al., 2013). Second, the category ‘activation of prior knowledge’ captures whether the students’ prior knowledge is activated. This activation can be provided by the material or by the teacher, such as by implementing online quizzes at the beginning of the lesson. This prior knowledge activation potentially supports the students to link the new information to their existing knowledge (e.g., Gurlitt & Renkl, 2010). Third, the category ‘initiating conceptual change’ assesses the extent to which students’ naïve conceptions or misconceptions are addressed during teaching to help students to develop a sophisticated mental model of the topic taught (e.g., Sinatra & Pintrich, 2003). This model development can, for example, be supported by virtual simulations that show the reaction of a chemical process. Fourth, the category ‘engaging self-explanation’ captures the extent to which students are encouraged to explain different concepts to themselves, their peers, fictitious others, or their teacher (e.g., Jacob, Lachner, & Scheiter, 2020). This can be realized, for instance, by asking the students to record a video explanation. Finally, the category ‘support of students’ self-discovery’ focuses on the extent to which students are encouraged to discover underlying concepts and relations. Therefore, this category assesses whether the students themselves are asked to link different concepts to each other or whether the teacher or the material provides the big picture. For example, students may have to gather the important information from web queries, or teachers may provide a worked-out educational text instead (e.g., Janssen, Westbroek, & van Driel, 2014).

However, especially in complex teaching situations such as teaching with technologies, constructivist learning activities should be accompanied by activities to support and scaffold students' learning (i.e., instructional support; Praetorius et al., 2018). Therefore, two categories which include indicators for instructional support from Hardy Jonen, Möller, and Stern (2006) were also adopted in this developed conceptualization. First, the category 'provision of guidance' captures the extent to which the teacher provides guidance to scaffold and support students' learning processes (e.g., Dennen & Burner, 2008). Second, the category 'provision of prompts/feedback' assesses if the teacher provides (individual) feedback to students such as follow-up prompts or information on the student's performance and knowledge gaps (e.g., Brookhart, 2011). In a second step in this dissertation, these categories for teaching and learning in mathematics were broadened to generic aspects of TET quality. For example, the category 'support of students' knowledge construction' was defined in a broad sense to be applicable to subject domains within science as well as within the humanities. Therefore, the category assessed the extent to which teachers supported students' discovery of the overall context of the lesson topics. For more information on how to apply these categories, see Study 1 for application in mathematics (Chapter 6) and Study 2 for domain-general applications (Chapter 7).

3 GENERIC PROFESSIONAL COMPETENCE OF TEACHERS

Research on teaching quality showed that the professional competencies of teachers are crucial determinants of teaching quality. Professional competence is defined as the skills, knowledge, attitudes, and further motivational variables (e.g., value beliefs, interest) that allow professionals such as teachers to master distinct tasks (Weinert, 2001). Therefore, professional competence is the ability to successfully accomplish a specific task, whereas performance is the actual achievement within the task (Klieme, Hartig, & Rauch, 2008). Especially in professional settings, such as teaching, the tasks can get very complex and therefore different aspects of professional competence have to be considered (Baumert & Kunter, 2006). However, early conceptualizations of teachers' professional competence mainly focused on the different dimensions of teachers' professional knowledge (Bransford, Derry, Berliner, Hammerness, & Beckett, 2005; Bromme, 1992; Shulman, 1986). Based on these models and on literature of professional competence, Baumert and Kunter (2006, 2013) established a more comprehensive understanding of teachers' professional competence (see Figure 2). This model encompasses aspects of generic professional competencies but does not consider aspects of technology-enhanced teaching (TET). So far, existing models that capture teachers' competencies for TET are not comprehensive as they focus on aspects of either professional knowledge (see technological-pedagogical-content knowledge—the TPACK model, Chapter 4.1) or motivation (see technology-acceptance model—the TAM, Chapter 4.2.2). Therefore, the aim of the present dissertation to comprehensively conceptualize the TET-related professional competencies of teachers was pursued by inter alia transferring aspects of the model by Baumert and Kunter to TET.

As depicted in Figure 2, the COACTIV model encompasses aspects of professional knowledge and additional aspects such as professional values and motivational orientations. As the COACTIV study was conducted in the domain of mathematics, the model exemplarily refers to domain-specific knowledge in mathematics, but can be transferred to other domains. The core of the model is the different domains of knowledge which constitute teachers' professional knowledge. Based on Shulman (1986) these dimensions are content knowledge (i.e., domain-specific knowledge of the subject taught), pedagogical content knowledge (i.e., knowledge on how to teach distinct content), and pedagogical/psychological knowledge (i.e., knowledge on how to design teaching and learning processes). In addition to these basic knowledge components, Baumert and Kunter (2006) included organizational knowledge (i.e., knowledge on how the educational system and its institutions work) and counseling knowledge (i.e., knowledge on how to talk to people outside of the system).

Besides these knowledge domains, there are three other aspects of professional competence within the COACTIV model: motivational orientations, value beliefs, and self-regulation. Baumert and Kunter include among teachers' *motivational orientations* facets such as their self-related cognitions, control beliefs, intrinsic motivation, and self-efficacy beliefs. Among these, self-efficacy beliefs have shown to be of utmost importance. The aspect *beliefs/values/goals* of the COACTIV model distinguishes between value-related valences, epistemological beliefs, subjective theories of teaching and learning, and goal systems. Kunter and Baumert further identified the aspect of professional self-regulation. According to this conceptualization, professional *self-regulation* encompasses the ability to responsibly manage one's personal resources. Especially within the teaching profession, teachers need to maintain a healthy distance to problems and obstacles during teaching, for example, to prevent being too involved in the social problems of the students. In the following, the most prominent aspects of the model are presented in more detail.

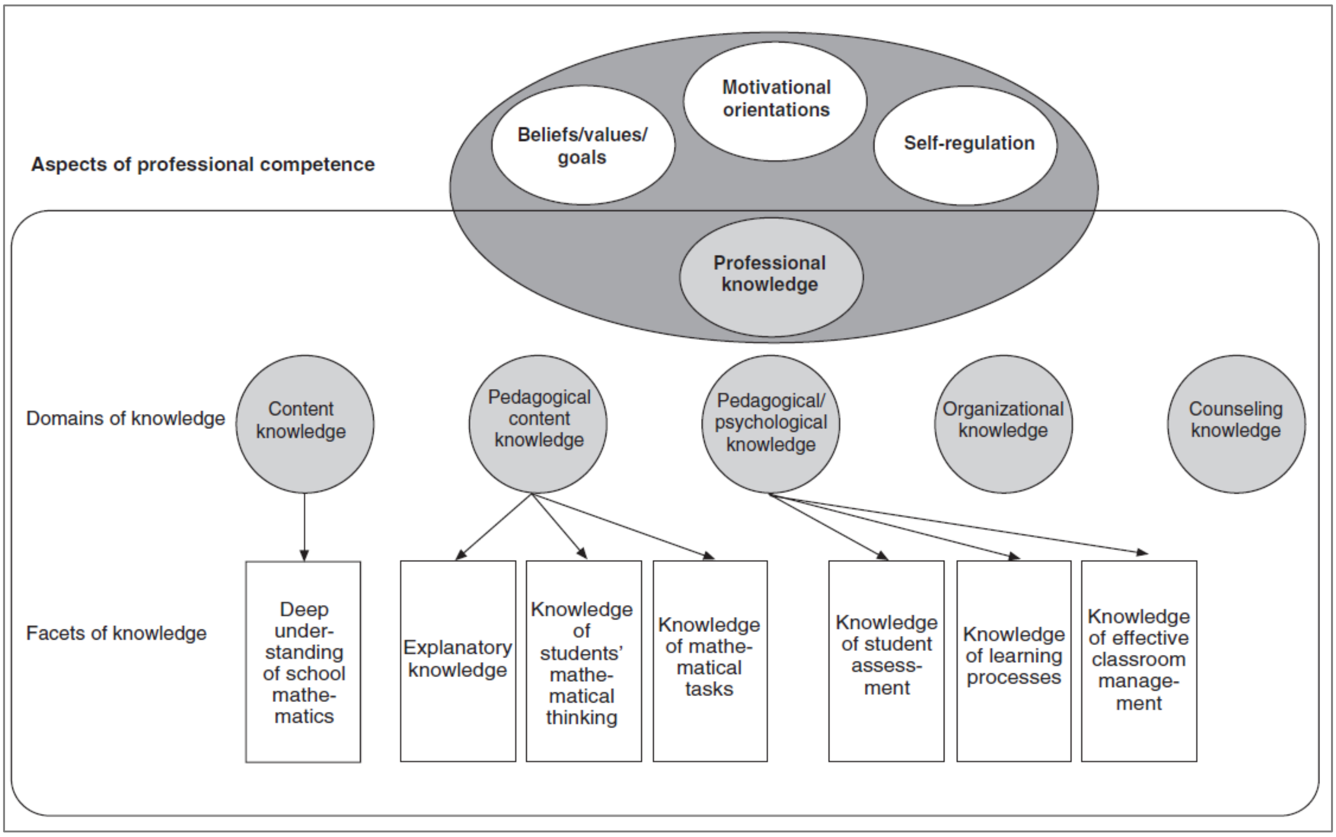


Figure 2. The COACTIV Model of Professional Competence, with the Aspect of Professional Knowledge specified for the Context of Teaching in Mathematics (Baumert & Kunter, 2013, p. 29)

3.1 Generic Professional Knowledge

It is commonly assumed that teachers gain their professional knowledge through formal teacher education programs at university and structured induction phases, but also through deliberate practice (Ericsson, 2006). Whereas during formal teacher education at universities pre-service teachers often gain isolated knowledge bases, these bases become gradually integrated and organized during daily teaching practice (Lachner, Jarodzka, & Nückles, 2016). An expert teacher therefore develops internalized scripts of different classroom scenarios which evolve to larger curricular units. This process potentially allows teachers with teaching experience to focus on individual students and simultaneously not lose track of the entire class. Based on this assumption, it might be the case that teachers with more teaching experience find it easier to add extra complexity to the teaching such as to try out new methods by integrating new technologies (Epstein & Hundert, 2002; Kane, 1992; Kunter et al., 2013; Lauermann &

König, 2016; Wolff, Jarodzka, & Boshuizen, 2017; Wolff, Jarodzka, van den Bogert, & Boshuizen, 2016).

Teachers' professional knowledge is commonly conceptualized as being composed of three major components—pedagogical, content, and pedagogical content knowledge—which will be presented in the following.

3.1.1 Pedagogical knowledge

Pedagogical knowledge (PK) is defined as the knowledge needed to design and implement teaching and learning across subjects (Shulman, 1986). This encompasses declarative as well as procedural knowledge of generic teaching methods and more specific aspects such as classroom management and classroom assessment (Voss, Kunter, & Baumert, 2011). Additionally, students' learning processes are always regarded as being situated in a specific classroom context of which teachers must be aware (Grossman & McDonald, 2008; Voss et al., 2011). Due to the crucial role of PK during teaching, pedagogical knowledge is an essential component in teacher education programs and is taught to (pre-)service teachers across domains. Within the COACTIV study, PK was more comprehensively termed as pedagogical/psychological knowledge (PPK), which highlights the need for a basic understanding of psychological phenomena such as student heterogeneity. Following this comprehensive conceptualization, Voss et al. (2011) identified five dimensions of teachers' PPK. First, *classroom management* encompasses knowledge about how to act in the classroom to prevent disturbances and sustain a smooth process of the lesson and therefore heighten the quantity of learning time. Second, *teaching methods* encompasses knowledge about how to productively use distinct teaching methods to pursue the objectives of the lesson and therefore heighten the quality of the learning time. Third, *classroom assessment* encompasses knowledge about when and how to apply different forms of classroom assessment. Fourth, *learning processes* encompasses knowledge of cognitive and motivational learning processes such as knowledge about learning strategies and the potential impact of prior knowledge. Last, *students' individual characteristics* encompasses knowledge about sources of students' heterogeneity in terms of cognitive, motivational, and emotional characteristics. Based on these dimensions, Voss et al. developed an instrument which consisted of 39 items. This test was answered within the COACTIV-R study by N = 746 teacher candidates (teachers who successfully graduated from a university teacher education program and who were in a structured induction phase at schools). The analyses showed that the PPK instrument was sensitive to differences in teacher candidates' teaching experiences and positively related to student ratings of instructional quality. Therefore, PPK was found to be an important knowledge component of teachers' professional knowledge.

3.1.2 Content knowledge

In the COACTIV study, content knowledge (CK) was conceptualized as teachers' understanding of the structure and underlying concepts of their subject (Krauss et al., 2008). This understanding should be much deeper than that of their students and the knowledge required to follow the curriculum. Therefore, CK includes knowledge of the relationships between the different concepts, including their similarities and differences. This encompasses the proof of concepts and the derivation of formulas. Even though this conceptualization differs significantly from the everyday mathematical knowledge of adults or good students, according to Krauss et al. teachers' CK does not include university-level mathematical knowledge that is not covered in the school curriculum. Krauss et al. developed a test instrument which encompassed 13 items of teachers' CK in relevant content areas in mathematics (i.e., arithmetic, algebra, and geometry; see Krauss et al., 2008, for details). This test was administered within the COACTIV study with 198 teachers from academic track schools (i.e., Gymnasien) and 113 from non-academic track schools (i.e., Real- Gemeinschafts- and Hauptschulen). The analyses showed that teachers who taught at academic track schools outperformed those teachers who taught at non-academic track schools. This is in line with the differences in the teachers' education as teachers who are allowed to teach at academic track schools have to attend more lessons for mathematicians at university than do teachers who are allowed to teach at non-academic track schools.

In contrast to the definition of CK as deeper knowledge of the school curriculum, Lachner and Nückles (2016) conceptualized teachers' CK as knowledge about higher mathematics. Therefore, in this conceptualization, subject-matter knowledge gained at university courses is in focus. In line with that conceptualization, they also developed a short multiple choice test to investigate the relation of expertise and quality of instructional explanations (*n* = 20 mathematics teachers, *n* = 15 mathematicians). First, the study showed that mathematicians had higher CK than the mathematics teachers. Second, CK was predictive for the quality of the instructional explanations meaning that mathematicians provided explanations of higher quality than teachers in mathematics.

In addition to these rather strict conceptualizations with regard to CK as mathematical knowledge, Loewenberg Ball, Thames, and Phelps (2008) conceptualized CK in a broader sense. The authors defined CK in mathematics "as the domain-specific mathematical knowledge needed to carry out the work of teaching mathematics" (p. 395). Therefore, CK encompasses not only domain-specific knowledge about distinct concepts but also how this knowledge can be taught to students so that they can make sense out of it and understand it. Therefore, this conceptualization is closely connected to teaching and, therefore, pedagogical content knowledge.

3.1.3 Pedagogical content knowledge

The term pedagogical content knowledge (PCK) was established by Shulman (1986). He theoretically conceptualized the amalgam of teachers' pedagogical knowledge and content knowledge as a crucial part of their professional knowledge (see Figure 3). According to this conceptualization, PCK enables teachers to teach a distinct content in a way that students can follow and learn.

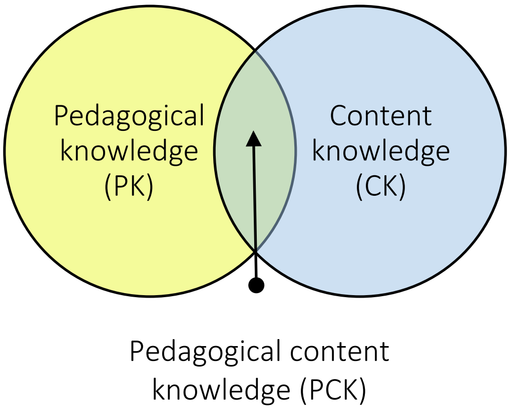


Figure 3. Pedagogical Content Knowledge as an Amalgam of Pedagogical and Content Knowledge.

Hill, Ball, and Schilling (2008) conceptualized teachers' PCK in mathematics. The authors highlighted that PCK is an additional independent knowledge component "apart from knowledge of the content itself" (Hill et al., 2008, p. 373). They further differentiated PCK into knowledge about content-related aspects and about students' knowledge, which results in discipline-specific knowledge of student learning. This discipline-specific knowledge of student learning could be distinguished into four categories: first, knowledge about common student errors, such as knowing which errors arise with the distinct content to be learned; second, knowledge about students' understanding of content, which encompasses knowledge on how to judge students' level of understanding; third, knowledge about student developmental sequences, which includes knowledge of how to classify the difficulties of tasks that students have to complete; and fourth, knowledge about common student computational problems, which includes knowledge about when and how students often struggle during computing. Based on this conceptualization, Hill et al. developed a test instrument to capture teachers' PCK. Factor analyses and accompanying interviews showed that aspects of students' mathematics thinking such as common student errors indeed constitute an independent knowledge component for teaching. This suggests that teachers in mathematics have knowledge beyond that of other experts in mathematics.

Within the COACTIV study, Krauss et al. (2008) developed a test instrument to capture teachers' PCK in mathematics. Based on a literature review, the authors identified three main components of PCK which they addressed in their test instrument: knowledge of mathematical tasks, knowledge of student misconceptions and difficulties, and knowledge of mathematics-specific instructional strategies. For example, knowledge of student misconceptions and difficulties was assessed by asking teachers to predict typical student errors or particular comprehension difficulties. Kunter et al. (2013) showed in the analyses of the COACTIV data that teachers with higher pedagogical content knowledge provided more cognitively activating tasks and more appropriate learning support. Therefore, the knowledge, for example, of students' misconceptions potentially enabled teachers to proactively address them which in turn positively influenced students' achievement gains.

In sum, from a theoretical and empirical point of view, PCK can be regarded as a complex, but crucial part of teachers' professional knowledge.

3.2 Generic Motivation

Motivation is the desire that guides individuals to start, direct, and sustain activities (Baumeister, 2016; Reeve, 2016). Within the overwhelming plethora of motivational theories, Eccles and Wigfield (2002) identified two different lines of theories that focused either on expectancies for success or on value beliefs. First, theories that focus on expectancies for success encompass aspects such as self-efficacy and control beliefs, whereas theories focusing on value beliefs include intrinsic motivation, self-determination, and interest. Baumert and Kunter (2006) also depicted this distinction in their model by differentiating motivational orientations and value beliefs.

3.2.1 Self-efficacy beliefs

Theories focusing on expectancy for success emphasize the importance of individuals' self-evaluation of their knowledge and perceived capabilities regarding a particular task to be performed. Therefore, the focus is not on the objectively measurable knowledge or skills but the individual perception of these. It is generally assumed that having a high expectancy of one's own knowledge regarding a task leads to persisting in the task even though obstacles are encountered (Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998). The most popular theory within expectancy research is Bandura's (1977) self-efficacy theory. Bandura (1982) defined self-efficacy as the confidence of the individual in his or her ability to successfully accomplish a given task. He furthermore states that this self-efficacy is a multi-dimensional construct that varies within individual between different levels of task complexity and highly depends on individuals' prior experiences and beliefs in fulfilling the task. Conceptually, self-efficacy models distinguish between beliefs about one's own competence in a certain domain (i.e., self-concept) and the expectancy of success on a specific task (i.e., self-efficacy). However, empirical research showed that these two different aspects are highly correlated and hardly separable and therefore are often used interchangeable (see Gaspard, 2015; Trautwein et al., 2012, for empirical investigations of students' self-efficacy).

Self-efficacy depends on an individual's perception and not on objective measures of task complexity. Accordingly, self-efficacy is commonly assessed via self-report measures in which individuals are asked to rate their degree of confidence in doing certain tasks (e.g., "Drive a car into the city" on a response scale ranging from 0 (*cannot do at all*) to 100 (*highly certain can do*); Bandura, 2006) or to rate their agreement with distinct statements (e.g., "When I am confronted with a problem in my job, I can usually find several solutions” on a response scale ranging from 1 (*not at all true*) to 6 (*completely true*); Rigotti, Schyns, & Mohr, 2008). It is generally assumed that individuals base their judgement of self-efficacy on four different sources: mastery experiences (e.g., ‘I successfully accomplished the task in the past’), vicarious experiences (e.g., ‘I see my colleagues succeeding in the task’), verbal persuasion (e.g., ‘My colleague tells me that I can succeed in the task’), and physiological arousal (e.g., ‘Getting nervous before doing the task’; Bandura, 1982, 2006). Tschannen-Moran and Hoy (2007) investigated teachers’ (N = 255) sources of self-efficacy in a survey study which included the *Teachers’ Sense of Efficacy Scale* (TSES; Tschannen-Moran & Hoy, 2001). The findings showed that especially novice teachers made use of different sources of self-efficacy when judging their teaching-related self-efficacy, whereas more experienced teachers mainly based their self-efficacy on their own past (i.e., mastery experiences as a source for self-efficacy).

3.2.2 Value beliefs

It is generally assumed that the personal value-related valences of a task are determined by intrinsic motivation which encompasses the individuals’ perceived interest and enjoyment during fulfilling a task (see also intrinsic value; Canning et al., 2018; Pekrun, Frenzel, Goetz, & Perry, 2007). Additionally, extrinsic factors such as the prospective achievement of a certain outcome determine individuals’ judgement of the personal value (c.f. extrinsic value; Pekrun et al., 2007). It is generally assumed that value-related valences encompass not only facets that are relatively stable across contexts (i.e., trait-like), such as the general interest in a certain topic, but also facets that are context-sensitive and situational (i.e., state-like), and thus vary across contexts, such as the perceived added value of doing a task within a certain setting. However, the extent of the cross-context stability or variability of these different facets of individuals’ values is currently debated within research (Eccles & Wigfield, 2002; Reeve, 2016; Su, Stoll, & Rounds, 2018). Eccles and Wigfield (2002) further differentiated value-related valences into four categories: costs (as possible negative consequences of a task), intrinsic value (as an affective value component), attainment value (as the personal importance of doing well in a task), and most importantly the utility value, which is often focused on in these theories (Gaspard, 2015). According to Eccles and Wigfield (2002), utility value emphasizes the subjective perceived usefulness of engaging in a task for achieving short- and long-term future goals. Therefore, an individual’s value influences not only the choice of a distinct task, but also the extent of engagement and performance within the task (see e.g., Canning et al., 2018, for effects of students' utility value of biological topics on their grades in biology).

3.2.3 Expectancy-value theory

The relation of teachers' self-efficacy and value beliefs on their behavior is captured in, for example, the expectancy-value theory. Whereas in the first expectancy-value models by Atkinson (1957, 1964) individual's value only indirectly influenced subsequent behavior via expectancies, modern expectancy-value theories assume that both self-efficacy and utility value are directly and concurrently related to behavior (see Figure 4). Research based on expectancy-value theory commonly assumes that individuals' self-efficacy and task-value beliefs directly determine the achievement performance, persistence, and choice in a given task. In this regard, expectancies and values are expected to be positively and reciprocally related to each other (see Figure 4). Therefore, from a theoretical point of view, a multiplicative effect can be assumed.

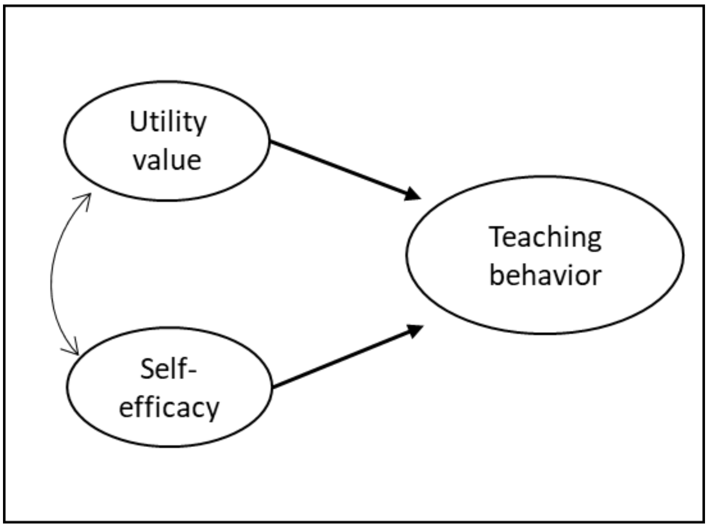


Figure 4. Direct Relations of Teachers' Self-Efficacy and Utility Value on Teaching Behavior based on the Expectancy-Value Theory.

Even though the expectancy-value theory gained popularity within teacher education research (e.g., Cheng & Xie, 2018; Green, 2002; Wozney, Venkatesh, & Abrami, 2006), research based on the expectancy-value theory was mainly conducted with students (Gaspard, Häfner, Parrisius, Trautwein, & Nagengast, 2017; Trautwein et al., 2012). The early empirical work investigating the relations of the two dimensions of self-efficacy and utility value and their effect on behavior were conducted in laboratory studies. In these studies, one of the two dimensions (i.e., either self-efficacy or utility value) was experimentally manipulated to be ‘zero’ in within-person designs. Based on these studies, the findings suggested that both self-efficacy *and* utility value have to be present to a certain extent and both influence the outcome positively. Therefore, an interactive term of both dimensions was proposed in the literature (Trautwein et al., 2012).

However, when applying expectancy-value theory to real-world outcomes with non-manipulated subjective expectancy and value beliefs, this interaction was often not considered. In contrast, in most cases additive effect models were applied. These models aimed at identifying between-person differences of engaging in the same tasks based on “naturally occurring differences in expectancy and value across different persons” (Trautwein et al., 2012, p. 765). One conceptual reason was that in real-world investigations it is unlikely that either self-efficacy or utility value of a specific task is (close to) zero, whereas the other is substantial, which would be a necessary prerequisite to detect these interactions (for a more detailed discussion, please refer to Trautwein et al., 2012). Therefore, potential interactions are likely to be small in real-world investigations. This led to the statistical reasoning that small interaction effects are only statistically detectable in very large samples in which latent interaction modeling is feasible (power analyses showed that minimum 1,000 participants are needed; Nagengast et al., 2011). However, research that had very large sample sizes based on international assessments investigating interaction effects showed that self-efficacy and value beliefs become more related to each other as the students grow older (Nagengast et al., 2011).

In sum, also in the case of teachers’ self-efficacy and utility value both should be positively related to each other and affect teachers’ behavior in the classroom such as their technology integration. However, the concrete interaction resulting in a multiplicative effect can only be modeled in very large samples. Recently, the expectancy-value theory became popular in teacher education to describe teacher behavior such as their attendance in professional development courses (Hwang, Hong, & Hao, 2018). For example, Watt and Richardson (2014) investigated in a comprehensive project in Australia (http://fitchoice.org) why pre-service teachers (*N* = 1651) choose to become a teacher. The study showed that, in line with the expectancy-value theory, pre-service teachers mainly chose to become a teacher when they were confident in their abilities and had high intrinsic value. This intrinsic value included aspects such as that they value their social contribution and the impact they can have on students’ lives through teaching them.

4 PROFESSIONAL COMPETENCE FOR TET

The general notion that knowledge and motivation are important when teaching is also acknowledged in the literature on teaching with technology. Previous research showed that not only teachers' *skill* variables but also their *will* variables are related to their technology integration. These aspects are summarized in the *will-skill-tool model* (Farjon, Smits, & Voogt, 2019; Knezek & Christensen, 2016; Petko, 2012). The will variables include teachers' attitudes and beliefs towards technologies in schools such as their perceived benefit of technologies for students' learning. Second, the skill variables include the skills of teaching with technologies such as knowledge about how to use technology and how to integrate technology into teaching. Third, the tool variables were found to be a further aspect for technology integration. They include the availability of technologies, such as the amount of technological devices in schools, and access, such as how the technology is maintained and how easily it can be used. Petko (2012) applied the will-skill-tool model within a survey of teachers (N = 357) in Switzerland. He found that 60% of the variance of teachers' technology use in school could be explained by the three different variables. In line with that, Farjon et al. (2019) investigated if the will-skill-tool model also explains variance in beginning teachers' frequency of technology integration (N = 398). The authors also found that 60% of the variance of teachers' technology integration could be explained through the aspects of the model. Moreover, the study showed that the strongest predictors for technology integration were the will variables, whereas the tool variables exerted the weakest influence on technology integration (see also Chapter 2.1).

However, previous studies on teachers' competencies for technology-enhanced teaching had two major weaknesses: First, they focused mainly on a merely descriptive level and outlined the different aspects of teachers' competencies such as their knowledge and attitudes affecting technology integration (see also research on the role of pedagogical beliefs, Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012, or constructivist beliefs, Liu, 2011). Second, these studies were not based on a comprehensive theoretical framework. Therefore, the present dissertation established a link between generic models of professional competencies and boundary conditions of technology-enhanced teaching.

4.1 TET-Related Professional Knowledge

Teachers’ professional knowledge for technology-enhanced teaching (TET) encompasses not only the generic dimensions such as content knowledge and pedagogical knowledge, but also aspects of the use of technologies. This technological knowledge (TK) includes knowledge about how to handle these technologies, including its hardware and software. According to the prominent conceptualization of the TPACK model by Mishra and Koehler (2006), technological knowledge has to be integrated into the pedagogical and content knowledge (see Figure 5).

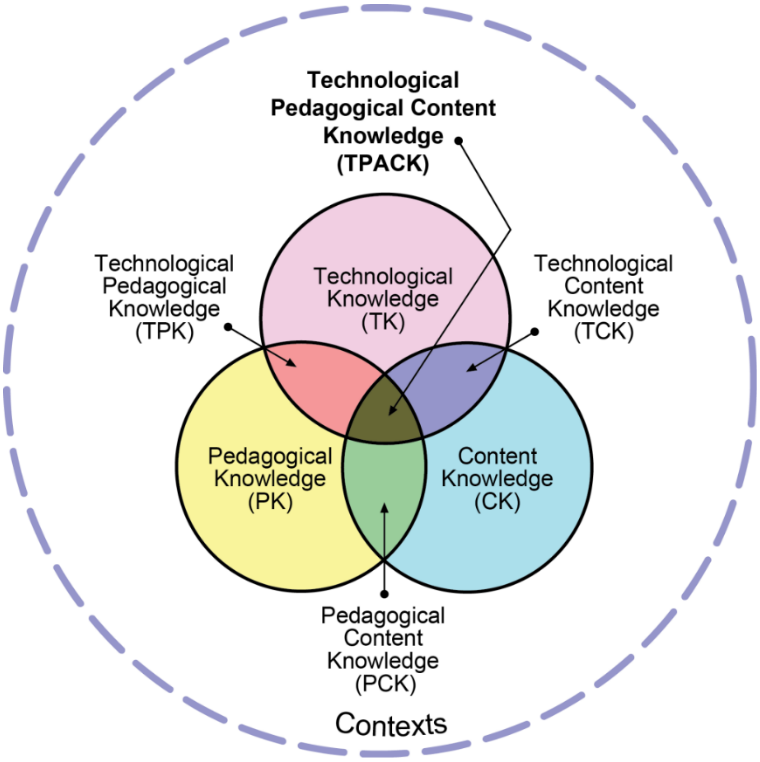
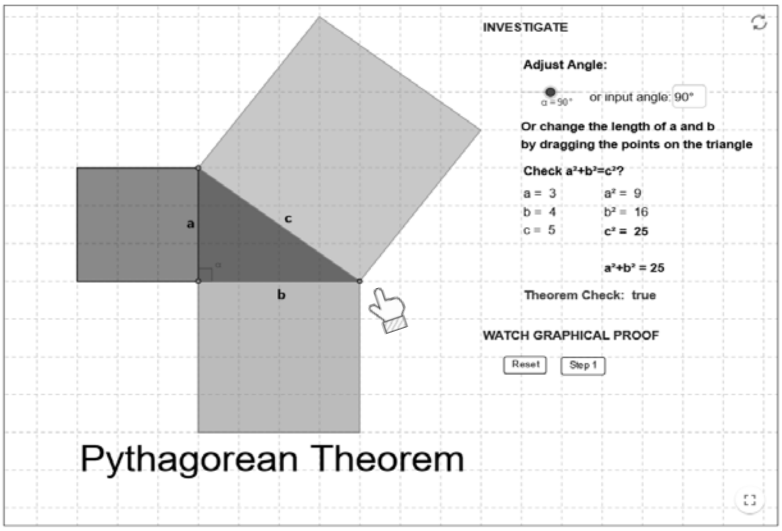


Figure 5. TPACK Model (Mishra & Koehler, 2006; © 2012 by tpack.org)

This integration results in three further technology-related, *T-components*: Technological pedagogical knowledge (TPK) is the knowledge about how to integrate technologies into distinct pedagogical methods. This encompasses, for example, the knowledge on how to implement technology-enhanced collaborative group work among students through appropriate technological tools (e.g., live-synchronized whiteboards, establishing a wiki). Technological content knowledge (TCK) is the knowledge about how to integrate technologies and domain-specific concepts. This includes, for example, the knowledge of how to best transfer accurate representations of different concepts into technology-rich environments (e.g., the visualization of photosynthesis in virtual simulations). Finally, there is *technological pedagogical content knowledge (TPACK)* which encompasses all knowledge components of teachers' professional knowledge. TPACK is therefore the knowledge of how to appropriately teach a distinct content with technologies. This knowledge requires an integration of pedagogical, content, and technological knowledge.

For example, in mathematics TPACK for teaching the Pythagorean Theorem ($a^2 + b^2 = c^2$) would be, from a pedagogical content knowledge view, the awareness that students struggle with the relation of a^2 as the associated side square of the side a and its representation in the formula. Students often get confused with the differences of a^2 and a as they do not understand the function of the exponent. Thus, teachers need to know that this difficulty can be addressed by distinct visualizations of the Pythagorean Theorem. For addressing this difficulty in technology-rich classrooms, the teachers additionally need to know that there are dynamic simulation software such as GeoGebra. With GeoGebra, teachers can design digital worksheets that encompass appropriate exercises and digital simulations to visualize the problem (see Figure 6 for an example). In this digital worksheet, students can change the size of the triangle by pulling one of the edges of the triangle, which results in an automatic change in the numbers of the side squares as well as the formula. Therefore, students get the connection between the pictorial and numerical representation more easily.



or input angle: 90°

Or change the length of a and b
by dragging the points on the triangle

Check $a^2+b^2=c^2$?

$a = 3$ $a^2 = 9$
$b = 4$ $b^2 = 16$
$c = 5$ $c^2 = 25$

$a^2+b^2 = 25$

Theorem Check: true

WATCH GRAPHICAL PROOF

Figure 6. GeoGebra Worksheet uploaded on Geogebra.org by the Users kdfedor and tommy.chan

4.1.1 Survey-based assessments of TPACK

Teachers' professional knowledge for TET based on the TPACK framework is mostly investigated using self-report questionnaires as they allow for a money and time efficient large-scale assessment (Lachner et al., 2019a; Scherer et al., 2019). The most popular and most frequently used questionnaire to capture self-reported TPACK was developed by Schmidt et al. (2009; for alternatives see e.g., Archambault & Crippen, 2009; Tondeur, Scherer, Siddiq, & Baran, 2017). The questionnaire comprises questions for all the seven dimensions of the TPACK construct (i.e., 8 items for TK, 10 items for PK, 17 items for CK, 15 items for TPK, 8 items for TCK, 8 items for PCK, and 9 items for TPCK). All 75 items are assessed using a 5-point Likert Scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). An example item for CK is "I have sufficient knowledge about mathematics", for TCK is "I know about technologies that I can use for understanding and doing mathematics", and for TPK is "I can choose technologies that enhance the teaching approaches for a lesson." However, studies investigating the factorial structure of TPACK based on this questionnaire showed mixed results. On the one hand, there are some studies that identified the presumed 7-factorial structure (e.g., Castéra et al., 2020; Lin, Tsai, Chai, & Lee, 2013). Contrarily, most of the studies identified different amounts of factors such as only one factor for covering all TPACK dimensions (Archambault & Barnett, 2010) or varying numbers of independent knowledge dimensions (e.g., two-factor structure: Scherer et al., 2017, or four factors: Koh, Chai, & Tsai, 2010). In addition to classical factor analyses, more complex analyses by Scherer et al. (2017) showed a nested factor structure of teachers' TPACK. This nested structure encompassed an underlying, general TK dimension on how to use technologies and specific subdimensions based on the skills needed for distinct actions in a technology-enriched classroom (e.g., evaluating adequate technologies for distinct pedagogical methods, representing TPK, or distinct content, TCK).

Despite these methodological concerns, the questionnaire and its modifications are used to investigate the relation of TPACK and additional teachers' characteristics such as gender (for an overview see Chai, Koh, & Tsai, 2016). For example, in a meta-analytic approach Ergen, Yelken, and Kanadli (2019) showed that male teachers reported higher TK, TPK, TPCK, CK, PCK, and TCK than female teachers, whereas female teachers reported higher PK (see Lin et al., 2013, for related findings). Other studies showed that younger teachers perceived more knowledge in the TK-related dimensions, whereas on the classic dimensions of professional knowledge (e.g., CK, PCK), older teachers perceived higher knowledge (Castéra et al., 2020; see Koh et al., 2010; Lee & Tsai, 2010; Lin et al., 2013, for related studies investigating relations of TPACK and age). In contrast, Koh and Chai (2011) found no significant differences in TPACK of Singaporean teachers with regard to their gender and age.

The mixed findings regarding the factorial structure of TPACK and its relations to teachers' characteristics could be attributed to the differences in contexts across studies (e.g., cultures, educational systems, experience levels of teachers, teacher domains). For example, Ergen et al. (2019) predominantly included studies with Turkish teachers which might confound the found relations. Another reason for the mixed findings might be the bias resulting from the application of self-report measures. Even though these self-report measures constitute an economic approach in large-scale assessments, they may have only partially depicted the actual availability of technology-related knowledge. This could probably be due to social desirability or potential metacognitive biases while judging one's own knowledge (Archambault & Crippen, 2009; Brinkley-Etzkorn, 2018; Koh, 2013; Lachner et al., 2019a; Scherer, Tondeur, Siddiq, & Baran, 2018). The discrepancy of teachers' self-reported TPACK and actual performance was, for example, empirically investigated by Kopcha, Ottenbreit-Leftwich, Jung, and Baser (2014). They examined the convergent and discriminant validity of pre-service teachers' (N = 27) self-report data (based on Schmidt et al.'s, 2009, questionnaire) and conducted content analysis of preservice teachers' lesson planning documents. Results revealed low convergence levels within similar constructs (e.g., self-reported TPK and TPK expressed in the lesson plan) and a lack of discrimination between unequal constructs (for further empirical investigations of validity of TPACK questionnaires, see Akyuz, 2018; Krauskopf & Forssell, 2013; So & Kim, 2009). Whereas for specific knowledge components, such as technological knowledge (TK), self-reports have been demonstrated to be valid indicators of teacher knowledge, for complex and integrated knowledge structures (e.g., technological pedagogical knowledge), self-assessments become more error-prone, which potentially results in biased estimates of teacher knowledge (Akyuz, 2018; Hargittai, 2005; Lachner et al., 2019a; Scherer et al., 2018). Therefore, recently, the TPACK self-report questionnaires have been discussed as depicting self-efficacy beliefs rather than objective knowledge (Lachner et al., 2019a; Scherer et al., 2018).

4.1.2 Alternative approaches to assess TPACK

To address the validity issues of self-report questionnaires, two alternatives are suggested in the literature: 1) test-based performance-oriented assessment tools and 2) measurement of performance in vivo (i.e., in the actual situation). Lachner, Backfisch, and Stürmer (2019a) developed one of the first test-based instruments to assess TPK as a domain-general aspect of teachers' TET-related knowledge. This performance-oriented assessment tool consists of two different sections. The first section encompasses questions about the different concepts of the conceptual knowledge. These questions are related to key principles of technology-enhanced teaching (TET) such as relevant facts and concepts (e.g., cognitive load theory, cognitive theory of multimedia learning). The second section consists of questions on situational TPK. This section uses short text-based vignettes that ask teachers to judge the appropriateness of integrating distinct technological tools into potential pedagogical approaches. In a first study, the test showed to be a meaningful approach to differentiate between teachers of differing teacher expertise levels ($N = 284$). A second study showed that the identified TPK of in-service teachers ($N = 120$) was related to their pedagogical knowledge, but not to their technological knowledge (both measured with established test instruments). This finding highlights the importance of pedagogical knowledge for meaningful technology integration into teaching.

The second alternative to address the validity issues of self-report questionnaires is actual performance-based measures. As a systematic investigation of teachers' teaching behavior in the classroom is very complex to realize, lesson plans and designed activities are often analyzed. For this purpose, rubrics and category schemes were developed to capture TPACK represented within these documentations in a situated and objective manner (Angeli & Valanides, 2009; Harris, Grandgenett, & Hofer, 2010; Jonsson & Svingby, 2007; Koh, 2013). However, most rubrics are focused on the extent to which the technology integration meets technology or content standards of policy makers and are therefore very technological-driven (see Angeli & Valanides, 2009; Harris et al., 2010). The first rubric, which also encompasses aspects of meaningful technology integration into teaching and learning processes, is the rubric by Koh (2013). This rubric sought to capture TPACK based on teachers' abilities to design technology-based learning activities. Therefore, the learning activities are examined on five dimensions of technology integration: active, constructive, authentic, intentional, and cooperative. Each dimension is rated on a five-point scale to address the meaningfulness of technology integration within the lesson. For example, for the dimension *active* the rubric assesses how long the given tasks engage students to manipulate information about subject matter with technologies. Moreover, Akyuz (2018) recently developed a category scheme that sought to capture the different components of TPACK in lesson plans of pre-service teachers in mathematics (N = 138). During a university course about teaching geometry with dynamic geometry applications, the pre-service teachers designed three to four lesson plans (N = 486 lesson plans). Each lesson plan was analyzed based on a category scheme that represented the different components of the TPACK model. Each category was rated dichotomously (i.e., category applied yes or no). For the component of PCK, for example, the lesson plan was analyzed with regard to different teaching approaches such as if real-world examples and multiple representations were implemented. With regard to TPK, the lesson was analyzed on whether students were prompted for different solutions with the dynamic geometry application. With regard to TPACK, the lesson plan was analyzed on whether technology was used as an enabler to make conjectures or generalizations. By applying a factor analysis with the gained ratings, the authors identified four, partially overlapping factors: one general factor encompassing the components CK, PK, and PCK; one TPACK factor with focus on content knowledge encompassing the components CK and TPACK; one TPACK factor with focus on pedagogical knowledge encompassing PK, TPK, and TPACK; and finally one factor that solely encompassed TK. These findings give first hints that the different components of the TPACK model are also detectable in lesson plans. However, it might be reasonable to also aggregate all TPACK components into one factor except for TK which seems to be outstanding (for related findings, see Scherer et al., 2017).

From a theoretical point of view, it is interesting that Koh (2013) and other authors who developed assessment approaches of TPACK equate teachers' performance in these approaches with their existing TPACK. According to this rationale, solely TPACK enables teachers to integrate technologies into their teaching in a meaningful way. However, this is not in line with generic models of teachers’ professional competence (e.g., Baumert & Kunter, 2006; Helmke, 2017), nor with research on TET (e.g., Farjon et al., 2019; Petko, 2012). This research showed that it is not only teachers’ actual TPACK, but also their motivation that influences their technology integration (Farjon et al., 2019; Knezek & Christensen, 2016; Petko, 2012; see also the discussion on hot cognition by Sinatra, 2005).

4.2 TET-Related Motivation

Previous research such as research based on the will-skill-tool model showed that teacher motivation plays a crucial role in technology-enhanced teaching (TET). In this regard, mainly teachers' *self-efficacy* beliefs regarding TET, such as their confidence in teaching with technologies, and their *value beliefs*, such as their perceived utility value of integrating technologies, were examined.

4.2.1 Self-efficacy and value beliefs regarding TET

Self-efficacy beliefs regarding TET refer to the conviction of teachers that they can use technology effectively as a means for teaching. For example, ICILS 2013 and 2018 investigated self-efficacy beliefs by asking the teachers to rate how well they can do different technology-related tasks (rating scale: "I know how to do this," "I haven't done this but I could find out how," "I do not think I could do this"). Most teachers reported that they know how to find useful teaching resources on the internet (95%) and how to produce presentations (84%), however fewer teachers reported that they know how to conduct more complex tasks such as using learning management systems (59%). (See Table 2 for data of Germany and the participating Scandinavian countries.) While teachers' self-efficacy in using technologies for teaching was high on international average, this self-efficacy varied considerably across countries. Teachers from Denmark had the highest technology-related self-efficacy, whereas teachers from Germany reported lower confidence in their skills. Further analyses showed that teachers who reported a daily use of technologies for teaching had significantly higher scale scores for their technology-related self-efficacy (Fraillon et al., 2014; Fraillon et al., 2019).

Table 2

Teachers' Self-Efficacy regarding TET in ICILS 2018

	Confident to find teaching resources on the internet	Confident to produce presentations	Confident to use learning management systems
Germany	98 (0.4)	83 (1.4)	34 (2.0)
Denmark	99 (0.3)	90 (1.2)	80 (1.5)
Finland	96 (0.5)	75 (1.2)	62 (1.5)

Note. Numbers represent percentages of teachers who indicated that they are confident to do the task (standard errors are in parentheses).

The variation in self-efficacy across countries and individual teachers is likely due to different experiences with technology-enhanced teaching. These different experiences likely occur not only during formal teacher education that addresses the integration of technology to different extents, depending on the country, but also in daily practice at schools and outside of schools (Tondeur, Scherer, Siddiq, & Baran, 2020). Sources of teachers' self-efficacy regarding technology-enhanced teaching were researched, for example, by Barton and Dexter (2019). They interviewed six middle school teachers in mathematics and science from two schools. The analysis showed that sources of teachers' self-efficacy for technology-enhanced teaching included verbal persuasion (i.e., getting acknowledgement from colleagues or principals for their own technology-enhanced teaching), vicarious experiences (i.e., seeing colleagues successfully teaching with technologies), and mastery experiences (i.e., personal experience of competence through successful teaching with technologies).

As teaching with technologies requires different knowledge components (as conceptualized in the TPACK framework), teachers' self-efficacy towards technology integration should presumably also be conceived as a multidimensional construct (see Bandura, 2006, for discussion of multidimensional self-efficacy constructs). In particular, teaching with technologies encompasses different knowledge dimensions associated with the different sub-tasks of technology integration. For example, TK self-efficacy is the individual expectancy to be able to handle the hardware of technologies, TPK self-efficacy is the individual expectancy to be able to apply meaningful technology-enhanced pedagogical methods, and TPACK self-efficacy is the individual expectancy to be able to teach distinct domain-specific content with technologies. Therefore, the questionnaire by Schmidt et al. (2009) was recently discussed as depicting dimensions of self-efficacy beliefs needed for teaching with technologies rather than teachers' actual ability of teaching with technologies (Kiray, 2016; Lachner et al., 2019a; Scherer, Tondeur, Siddiq, & Baran, 2017; Scherer et al., 2018). For example, Scherer et al. (2017) adapted and shortened the questionnaire by Schmidt et al. (2009) to assess pre-service teachers' self-efficacy beliefs in the technology dimensions (T-dimensions: TPCK, TCK, TPK, and TK). Pre-service teachers were asked to indicate their agreement with statements that presented aspects of their self-efficacy beliefs on the four T-dimensions. In line with Schmidt et al. (2009), a five-point response scale was administered that ranged from 0 (*I completely disagree*) to 4 (*I completely agree*). TPACK self-efficacy assessed with this questionnaire showed to be positively related to teachers' utility value of educational technologies.

In addition to teachers' self-efficacy, their *value beliefs* towards teaching with technologies are regarded as a crucial part of teacher motivation for TET (Fraillon et al., 2014; Petko, 2012). In line with generic models of value beliefs, the value beliefs towards teaching with technologies can be distinguished in the subjective perceived usefulness of engaging in a task for achieving short- and long-term future goals (see Eccles & Wigfield, 2002). A short-term goal of teaching with technologies would be to foster teaching and learning processes in a specific lesson. Therefore, the associated belief would be that these teaching and learning processes can be enhanced through using technologies. In addition, a long-term goal of technology integration would be that students are able to participate in the digitized society though daily technology use in schools. The associated belief would be that students need these 21st century skills.

For example, van Braak, Tondeur, and Valcke (2004) investigated the associations of teachers' utility value of educational technologies and their frequency of technology integration based on a survey (N = 468 primary school teachers). Within the survey, the authors assessed the utility value of educational technologies for teaching and learning processes (e.g., "I find technologies beneficial for my teaching practice.") and the utility value for more comprehensive long-term goals (e.g., "I believe a progressive introduction of technology into education responds to our society's changing needs."). In addition, they assessed the self-reported frequency of technology use for teaching and further demographic data. The analyses showed that besides teachers' experience with technologies and their gender, mainly teachers' utility value of educational technologies predicted the frequency of technology integration for teaching. This finding suggests that teachers' utility value for teaching with technologies also influences their behavior with regard to technology integration (see Sang, Valcke, van Braak, & Tondeur, 2010; Teo, Huang, & Hoi, 2018, for similar findings). However, the extent to which teachers perceive this utility value of integrating technologies largely varies between teachers and might also vary within teachers from one lesson to another.

Besides research that investigated the relations of teachers' self-efficacy and value beliefs with technology integration in an isolated manner, there is research that investigated the effects simultaneously. For example, there are first attempts in applying generic models of motivation, such as the expectancy-value theory, to research on technology-enhanced teaching (TET). An empirical example can be found in the study by Wozney and colleagues (2006). In a cross-sectional study with 764 primary and secondary teachers, the authors investigated the relations of teachers’ self-efficacy and perceived utility on their technology integration. In line with expectancy-value theory, the authors found that both teachers’ self-efficacy and utility value were directly related to their frequency of technology integration. However, this pattern could not be replicated in further studies. For instance, Taimalu and Luik (2019) examined how the motivation of teacher educators ($N = 54$) impacts their technology integration in a questionnaire study. The authors showed that only teachers’ technology-related self-efficacy and not their utility beliefs had a direct effect on their technology integration. However, both studies investigated teachers’ technology integration using only rather distal measures (e.g., frequency of technology integration). This is remarkable as the expectancy-value theory explicitly refers to the performance, persistence, and effort individuals invest in a task and therefore addresses qualitative aspects of behavior (Eccles & Wigfield, 2002). Therefore, it should be further investigated whether teachers’ self-efficacy and utility value of educational technologies are also related to the quality of technology integration such as the use of distinct potential for teaching and learning processes.

4.2.2 Technology-acceptance models

Besides general motivational belief models which can be transferred to the field of teacher motivation and their technology integration, there are also models that were developed in the field of technology adoption across contexts (Davis, 1989; Teo, 2009, 2011). These models are summarized under the term *technology-acceptance models* (TAM).

Within these models, teachers’ value beliefs for integrating technologies are distinguished into individual utility value and perceived usefulness, which are defined as core variables determining technology integration (Scherer & Teo, 2019). Most of these models and theories have evolved from consumer research and management information systems research to explain, for example, why some employees use a distinct innovation such as new digital information report system and others do not (Davis, 1989). Therefore, these models, traditionally, do not focus on the use of technologies but on the acceptance of these new technologies, which is assumed to lead to their actual use. Nowadays, there are several applications of TAM within research in teacher education as they have demonstrated to be powerful models for explaining differences in teachers' technology adoption and are easy to implement in empirical studies (Scherer, Siddiq, & Teo, 2019). Therefore, in the context of technology-enhanced teaching, various models such as the unified theory of acceptance and use of technology (UTAUT; Venkatesh, Morris, Davis, & Davis, 2003) or the technology acceptance model (TAM; e.g., Scherer & Teo, 2019; Scherer et al., 2019) are frequently used to predict teachers' behavioral intentions when using technology and the frequency of technology adoption (for an overview, see Taherdoost, 2018). These models summarize various aspects of teachers' motivational beliefs that are directly or indirectly related to teachers' behavioral intentions in using technology and ultimately to their technology integration.

The TAM differentiates motivational beliefs into variables that are directly related to teachers’ technology use such as their perceived usefulness, ease of use, and attitudes towards technology, which are called *core variables* of the model. Furthermore, the TAM defines variables that are only indirectly related to technology integration. These variables are so-called *external factors* and subsume aspects such as teachers' self-efficacy beliefs and facilitating conditions of technology use that may explain differences in perceived usefulness and attitudes (Teo, 2011). This differentiation of motivational beliefs reflects the assumption that some beliefs may be more or less important in determining technology integration. In other words, the TAM postulates a sequential relationship that follows a cascade in which, for example, self-efficacy predicts perceived utility and perceived utility predicts technology integration. Therefore, motivational beliefs are categorized into variables with direct effects (e.g., perceived utility) and indirect effects (e.g., self-efficacy) on technology integration (see Figure 7).

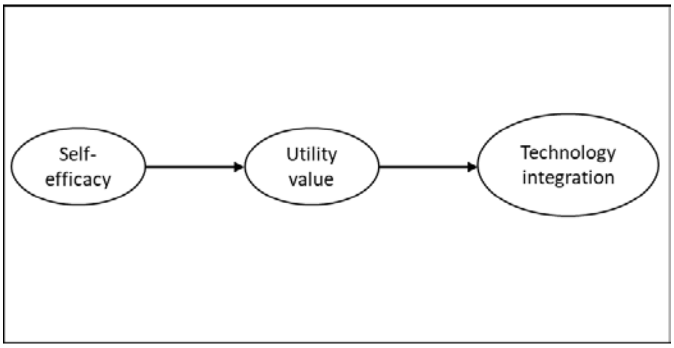


Figure 7. Cascade Mechanism of Self-Efficacy on Utility Value based on the Technology Acceptance Model.

Scherer and Teo (2019) analyzed 45 studies that examined the effects of the TAM core variables on teachers’ behavioral intention when using technologies. The analysis of the model comparison showed that the model that included a direct relation between the perceived usefulness of educational technologies and the behavioral intention of teachers to use the technologies fit the data of the studies significantly better than a model that assumed only indirect effects of the perceived usefulness on attitudes and attitudes on behavioral intention. Therefore, a direct link between teachers’ perceived usefulness of technologies and their technology integration is proposed (Figure 7). Additionally, Scherer et al. (2019) conducted a meta-analysis of TAM-related research, extended by external variables such as teachers' subjective norms and self-efficacy beliefs based on 114 studies. The authors showed that self-efficacy was linked to the core variables of the TAM model (e.g., utility value) and concluded that teachers' self-efficacy should be further investigated, as it may serve as a barrier or enabler for their technology integration. Therefore, self-efficacy should be considered not only as an external variable that indirectly influences teachers’ behavioral intention to use technology via their perceived usefulness (as in traditional TAM), but also as a variable that directly influences the technology integration of teachers. However, this mechanism should be further empirically investigated.

Overall, the empirical and theoretical findings on the relation of teacher motivation and technology integration show that this relation exists; however, the actual mechanism of teacher motivation and technology integration is yet unclear. This could be due to the fact that the two alternative lines of research are mostly separate. First, research informed by general motivational beliefs research (Eccles & Wigfield, 2002; Reeve, 2009) assumes direct and simultaneous effects of teachers’ self-efficacy and utility value on their technology integration and therefore a *concurrent mechanism*. Alternatively, research which is more technologically-driven such as the technology-acceptance model assumes a *cascade mechanism* of the different components of teacher motivation on (the acceptance of) technology integration (Davis, 1986; Teo, 2011). Thus, the present dissertation systematically examined the different mechanisms of teacher motivation and their technology integration in order to provide a comprehensive framework on boundary conditions of technology integration.

5 OVERVIEW OF STUDIES

5.1 Framework for Studies

The literature review showed two major weaknesses of existing literature: First, there is no comprehensive conceptualization of technology integration in the classroom. Second, even though there are well-defined models of teachers' generic professional competencies, there is no comprehensive framework of teachers' professional competencies for technology-enhanced teaching. Recently, however, the first comprehensive framework in this respect, the *opportunity-to-learn model in technology-enhanced classrooms,* was published by Lachner, Stürmer, and Scheiter (2020; see Figure 8). Generic opportunity-to-learn models are very prominent in German educational science to describe the complex system of teaching and learning in the classroom (in German: Angebots-Nutzungs-Modelle; see Helmke, 2017; Seidel, 2014, for different variations of opportunity-to-learn models). The main claim of these models is that teachers have to provide learning 'opportunities' for their students (e.g., provide appropriate worksheets) and their students have to make use of them and have 'to learn' with them (e.g., elaborate on the exercises on the worksheet). Teachers can use different learning materials and approaches to improve the quality of their provided learning opportunities and to facilitate students' learning. However, teachers can only provide an opportunity to their students and it is up to the students to learn from and with it. Teachers therefore need the appropriate competencies to tailor their teaching as closely as possible to their students' prerequisites, such as their subject-specific prior knowledge, so that students can easily make use of the learning opportunities offered.

In line with these generic models, Lachner et al. (2020) postulated that teachers can enrich their provided learning opportunities by a meaningful technology integration in teaching processes as well as in teaching and learning materials. In this dissertation, I examined this technology integration based on my newly established conceptualization of technology integration with regard to three aspects (see Figure 8, italized aspects): First, the quantity of technology integration was examined across several lessons (Study 2) and in general during teaching (Study 3). Second, the quality of technology integration was analyzed with regard to the technology-enhanced teaching quality and technology exploitation (Study 1 and Study 2).

To be able to implement the complex technology-enhanced learning opportunities, teachers need distinct professional competences. In line with generic models of teacher competencies, I further differentiated these competencies into professional knowledge (e.g., CK, PCK; Baumert & Kunter, 2006) and additionally the distinct dimensions of the TPACK model (e.g., TK, TPK; Mishra & Koehler, 2006). Teacher motivation was examined with regard to both generic models of motivation such as the expectancy-value theory (Eccles & Wigfield, 2002) as well as specific models such as technology-acceptance models (Scherer et al., 2019).

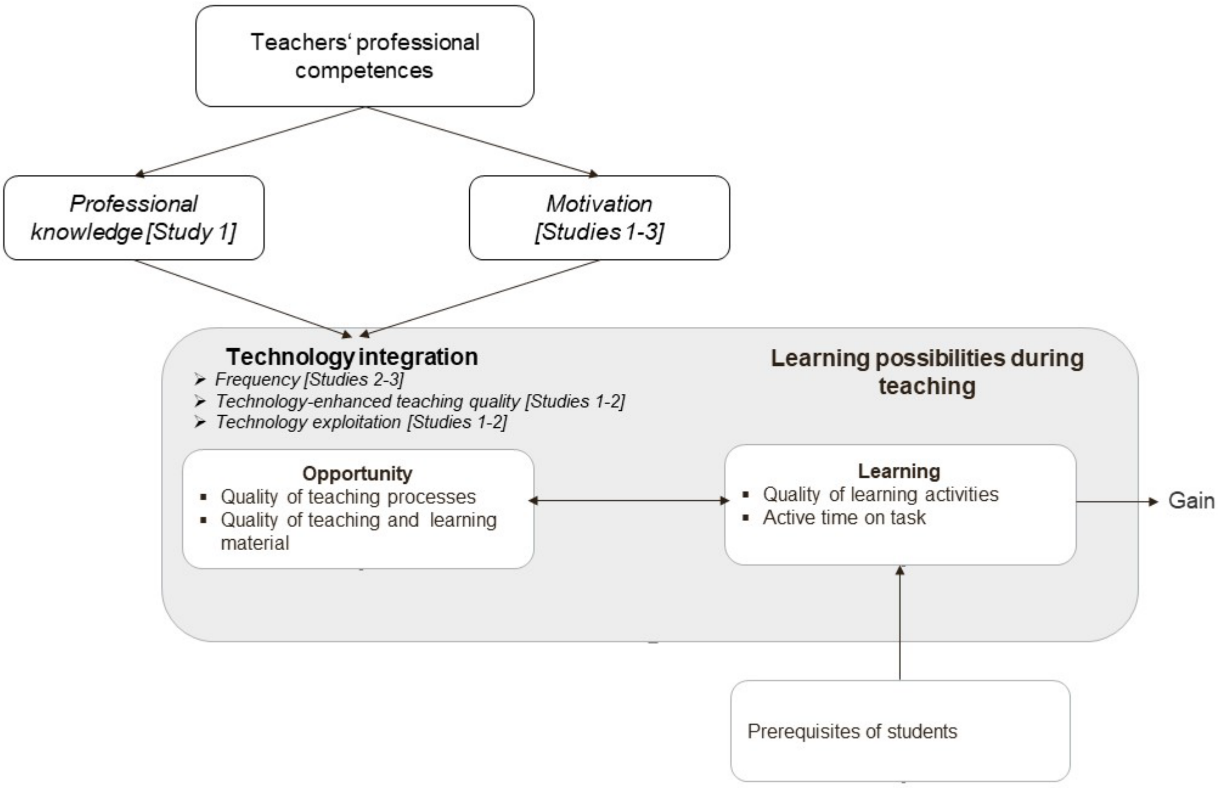


Figure 8. Opportunity-to-Learn Model for Technology-Enhanced Teaching based on Lachner et al. (2020) with Extended Aspects investigated in the Present Dissertation.

Note: Extended Aspects made in the dissertation are in *italics*, and the present dissertation studies (1-3) in which they are examined are listed.

Besides the teacher variables, which are the focus of the present dissertation, the opportunity-to-learn model in technology-enhanced classrooms defines the broader context in which teaching takes place. The model postulates that teachers can only provide learning opportunities such as learning tasks. However, the quality of the learning activities based on these tasks and active time spent on the tasks is determined by students' prerequisites. All these complex mechanisms of learning opportunities and learning activities constrain the outcome which is defined as students' learning gain. These aspects were not directly investigated in the present dissertation; however, they were considered during design, analyses, and interpretation of the empirical investigations. Additionally, to account for potential impact of instructional context factors, the empirical studies were conducted in different contexts. The two initial studies were conducted in Germany. Whereas in the first study teachers from regular teacher education programs and regular schools participated, in the second study only teachers from technology-rich schools took part. The third study was conducted in a different educational system, namely Norway, and teachers who taught in technology-rich schools participated.

5.2 Overview of Studies and Research Questions

First, in a quasi-experimental approach I investigated the relations of teachers' competencies and the quality of technology-enhanced lesson plans (*N* = 94; Backfisch, Lachner, Hische, Loose, & Scheiter, 2020a). This approach allowed me to establish a comprehensive conceptualization of the quality of technology-enhanced teaching with clearly defined indicators. Furthermore, I investigated the relative role of teachers' skill and will on their quality of technology-enhanced teaching (TET). More precisely, I examined whether and how teachers' professional knowledge and motivational beliefs—as crucial facets of their professional competence—have differential effects on the quality of technology integration within mathematics lesson plans depending on teachers' relative levels of expertise. Accordingly, the main research questions (RQ) of Study 1 were

> ***RQ1***: Do advanced teachers (i.e., trainee and in-service teachers) provide better lesson plans in terms of instructional quality and technology exploitation than novice teachers (pre-service teachers)?
>
> ***RQ2***: Do teachers' professional knowledge (content knowledge, pedagogical content knowledge, and technological knowledge) and/or their motivational beliefs (TPACK self-efficacy, utility value) mediate the assumed effects of their relative expertise on instructional quality and technology exploitation?

Applying indicators of teaching quality and technology exploitation to technology-enhanced lesson plans showed reliable results. In line with general findings on relative teacher expertise (Baumert et al., 2010; Berliner, 2004; McIntyre, Mainhard, & Klassen, 2017), the analyses indicated that advanced teachers (i.e., trainee teachers and in-service teachers) designed lesson plans with higher instructional quality and higher levels of technology exploitation than novice teachers (i.e., pre-service teachers). Mediation analyses revealed that the effect of relative teacher expertise was mediated by the perceived utility of technologies for teaching but was not mediated by professional knowledge. Thus, teachers' perceived utility value played a crucial role for designing technology-enhanced mathematics instruction. However, two major questions remained open which were addressed in the subsequent two studies. First, the question remained open as to how exactly the utility value and technology integration relate to each other (e.g., which contextual aspects influence this relationship). Second, the question remained whether this relationship of teacher motivation and technology integration remains stable across contexts.

Therefore, in a second study, I further examined the relative role of different components of teacher motivation and quantity and quality of technology integration with an experience sampling approach (N = 18 teachers teaching in technology-rich classrooms). This approach allowed me, first, to apply the comprehensive conceptualization and indicators of technology-enhanced teaching quality to other subject domains and, second, to analyze the relation of teacher motivation and technology integration in a highly situated manner. Accordingly, the questions were pursued how teachers' motivation and their technology integration are related in authentic in-class technology use across subjects and lessons which led to the following main research questions of Study 2:

> ***RQ3***: Does the relation between teachers' motivation and their quantity and quality of technology integration vary over time?
>
> ***RQ4***: Does the individual level of self-efficacy and utility value predict the quantity and quality of technology integration?

Based on the analyses of teacher diaries using a mixed method approach, it was apparent that teachers' motivation and their technology integration varied over time. More in-depth analyses showed that teachers' utility value determined the quality of technology integration. Additionally, qualitative analyses showed that instructional contexts (e.g., materials used) affected the technology integration. In Study 1 and Study 2, teachers' perceived utility value accounted for the quality of technology integration, however, self-efficacy had no effects.

In a third study, I further analyzed the relations between teachers' self-efficacy, utility value, and technology integration with a survey among teachers (*N* = 524) teaching in a governmental initiative for full technical infrastructure in a Norwegian municipality. This study design allowed for examination of the relations of teachers' self-efficacy on their technology integration in a fine-grained manner and for investigation of the stability of the previous findings in a different educational system. I followed two divergent perspectives of theoretical reasoning which assume either a) a concurrent mechanism of teachers' self-efficacy beliefs and utility value based on expectancy-value theories (EVT) or b) a cascade mechanism following technology acceptance models (TAM) to investigate differential relations of self-efficacy and utility value on technology integration:

> ***RQ5***: How are teachers' TPACK self-efficacy and utility value related to the frequency of in-class technology use and the emphasis teachers put on developing students' digital literacy?

Regarding teachers' frequency of technology integration, latent structural equation modelling revealed that both the concurrent and the cascade models represented the data well. Based on additional analyses an integrated model was suggested which encompassed both direct and indirect relations of self-efficacy and technology integration.

6 *Study 1*: PROFESSIONAL KNOWLEDGE OR MOTIVATION?

Investigating the Role of Teachers' Expertise on the Quality of Technology-Enhanced Lesson Plans

The content of the following chapter was already published in Learning and Instruction. The proportional contributions of the different co-authors to the manuscript are presented in the subsequent table. This article may not exactly replicate the final version published in the journal. It is not the copy of record.

Author	Author position	Scientific ideas %	Data generation %	Analysis & interpretation %	Paper writing %
Iris Backfisch	first author	70 %	90 %	80 %	70 %
Andreas Lachner	second author	15 %	0 %	10 %	20 %
Christoff Hische	third author	0 %	5 %	10 %	0 %
Frank Loose	fourth author	5 %	5 %	0 %	0%
Katharina Scheiter	fifth author	10 %	0 %	0 %	10 %

Title of paper:	Professional knowledge or motivation? Investigating the role of teachers' expertise on the quality of technology-enhanced lesson plans
Status in publication process:	published: *Learning and Instruction*, 66, 101300 https://doi.org/10.1016/j.learninstruc.2019.101300

Backfisch, I., Lachner, A., Hische, C., Loose, F., & Scheiter, K. (2020). Professional Knowledge or Motivation? Investigating the Role of Teachers' Expertise on the Quality of Technology-Enhanced Lesson Plans. *Learning and Instruction, 66, 101300*, https://doi.org/10.1016/j.learninstruc.2019.101300

Abstract

In an expertise study with 94 mathematics teachers varying in their relative teacher expertise (i.e., student teachers, trainee teachers, in-service teachers), we examined effects of teachers' professional knowledge and motivational beliefs on their ability to integrate technology within a lesson plan scenario. Therefore, we assessed teachers' professional knowledge (i.e., content knowledge, pedagogical content knowledge, technological knowledge), and their motivational beliefs (i.e., self-efficacy, utility value). Furthermore, teachers were asked to develop a lesson plan for introducing the Pythagorean theorem to secondary students. Lesson plans by advanced teachers (i.e., trainee teachers, in-service teachers) comprised higher levels of instructional quality and technology exploitation than the ones of novice teachers (i.e., pre-service teachers). The effect of expertise was mediated by teachers' perceived utility value of educational technology, but not by their professional knowledge. These findings suggest that teachers' motivational beliefs play a crucial role for effectively applying technology in mathematics instruction.

6.1 Theoretical Background of the Study

“Technology can amplify great teaching, but great technology cannot replace poor teaching” (OECD, 2015, p. 4). This quotation succinctly illustrates that educational technology, which commonly refers to distinct hard-, but more importantly software, can contribute to students’ achievement, when it is adequately orchestrated in the classroom (e.g., Chauhan, 2017; Mayer, 2019; Puentedura, 2006; Zhu & Urhahne, 2018). At the same time, this quotation suggests that teachers require professional competencies to adequately use educational technology to support students’ learning. Against this background, research provided important empirical evidence, for instance, a) regarding the role of educational technology for initiating students-teacher interactions (e.g., Ligorio, Cesareni, & Schwartz, 2008; Narciss & Koerndle, 2008; Näykki, & Järvelä, 2008; Valanides & Angeli, 2008), b) regarding teachers’ professional knowledge for integrating technology (e.g., Mishra & Koehler, 2006; Scherer et al., 2019; Tondeur, Aesaert, Prestridge, & Consuegra, 2018), or c) regarding teachers’ motivational beliefs for using educational technology (c.f., technology-acceptance model, see Scherer et al., 2019; Teo, 2011). However, this research mostly analyzed the different dimensions in an isolated manner. The paucity of integrated research which directly investigates distinct relations between these motivational and cognitive conditions (i.e., professional competence), and their effects on the *quality* of integrating technology, however, is surprising (see also Kunter et al., 2013, for related discussions on general teaching quality).

Building off previous research on teaching quality (e.g., Baumert et al., 2010; Kunter et al., 2013) and research on relative teacher expertise (e.g., Berliner, 2001; Cortina, Miller, McKenzie, & Epstein, 2015; Herppich, Wittwer, Nückles, & Renkl, 2014; Lachner et al., 2016; Wolff, Jarodzka, van den Bogert, & Boshuizen, 2016), in this article, we investigated effects of professional knowledge and motivational beliefs (as constituents of professional competence) on instructional quality and technology exploitation. Therefore, we conducted an expertise study with mathematics teachers ($N = 94$) who differed in their relative teacher expertise (i.e., years of teaching experience, level of teacher education qualification). More specifically, we applied a scenario-based approach (for related approaches see Harris & Hofer, 2011; Kopcha et al., 2014; Kramarski & Michalsky, 2010), in which we asked the participating teachers to provide a lesson plan in which they described the potential use of technology for scaffolding students’ learning. This approach allowed us to heighten the internal validity of our findings (e.g., similar teaching context, same learning objectives), and at the same time, capture teachers' reasoning for technology integration in a situational and controlled manner.

5.2.1 Teachers' professional competence to use technology in the classroom

Previous research documented that in many educational systems teachers rarely use technology during teaching (e.g., Drossel, Eickelmann, & Gerick, 2017). Fraillon and colleagues (2014) examined teachers' implementation of educational technologies across 21 educational systems. The authors found that there were large discrepancies regarding the use of technology across the different educational systems. For example, only one third of the participating German teachers reported to regularly use technology during teaching – in contrast to 80% of the teachers from other countries like Australia. Additional analyses by Drossel et al. (2017) demonstrated that teachers' use of technology was only slightly predicted by the availability of technology (e.g., in Germany: $\beta = 0.09$). Therefore, the question remains what other factors besides the mere availability of technology account for teachers' technology integration.

Commonly, it is assumed that teaching behavior is strongly affected by the particular level of teachers' professional competence. Professional competence is generally defined as the professional knowledge and motivational beliefs that provide the basis for mastering specific professional situations (see Epstein & Hundert, 2002; Kane, 1992; Kunter et al., 2013; Lauermann & König, 2016). The availability of both professional knowledge and adequate motivational prerequisites seems also important for teachers' technology integration (e.g., Farjon et al., 2019; Knezek & Christensen, 2016; Petko, 2012).

Teachers' professional knowledge to use technology

Regarding the use of educational technology, TPACK is a prominent and frequently used framework which allows to describe teachers' professional knowledge for effectively integrating educational technology in the classroom (Koehler & Mishra, 2009). TPACK is based on the general knowledge framework by Shulman (1986) who proposed three knowledge components which are critical to enhance teaching quality in general (see also Baumert et al., 2010; Hill et al., 2008; Kunter et al., 2013 for empirical evidence): a) *Content knowledge* (CK) refers to teachers' domain specific subject matter knowledge; b) *pedagogical knowledge* (PK) constitutes the domain general knowledge which enables teachers "to create powerful learning opportunities” across domains (Voss et al., 2011, p. 953); c) *pedagogical content knowledge* (PCK), in contrast, constitutes knowledge about subject specific teaching representations and students’ (mis-)conceptions, which is necessary to make subject-matter knowledge comprehensible for students (Baumert et al., 2010; Hill et al., 2008; Shulman, 1986). In their TPACK framework, Mishra and Koehler (2006) added *technological knowledge* (TK) which refers to teachers’ professional knowledge of technologies such as educational technologies and handling of software. Adding technological knowledge resulted in three additional T-dimensions (Scherer et al., 2017), which are commonly associated with technology-enhanced teaching: *Technological content knowledge* (TCK) is regarded as knowledge about how to apply technology in subject specific content areas; *technological pedagogical knowledge* (TPK) regards teachers’ domain-general knowledge of how educational technology can be applied to support students’ learning during teaching (Koehler & Mishra, 2009; Lachner et al., 2019a; Scherer et al., 2018). Last, *technological pedagogical content knowledge* (TPACK) specifically refers to content specific teaching strategies with educational technology (Koehler & Mishra, 2009). Therefore, TPACK goes beyond operational knowledge about technology and is essential for integrating subject matter specific teaching processes with educational technology (see also Ligorio et al., 2008, Narciss & Koerndle, 2008; Valanides & Angeli, 2008, for related discussions on professional knowledge).

General research on (teacher) expertise which commonly contrasts experts to novices, demonstrated that acquiring such interrelated knowledge as TPACK requires ample amounts of deliberate practice. With repeated experience novice teachers’ isolated and basic knowledge structures become gradually integrated and organized (e.g., Berliner, 2004; Chi, Feltovich, & Glaser, 1981; Grossman & McDonald, 2008; Lachner & Nückles, 2016; McIntyre et al., 2017; Pauli & Reusser, 2003; Schmidt & Rikers, 2007). This knowledge re-organization enables expert teachers to realize high-quality instruction (Kunter et al., 2013; Malmberg, Hagger, Burn, Mutton, & Colls, 2010; Meschede, Fiebranz, Möller, & Steffensky, 2017).

However, to-date there is only limited empirical evidence on the factorial structure of these technology-related knowledge components and how these components are related to each other. Lin and colleagues (2013) investigated the relationships among the different TPACK components (i.e., CK, PK, PCK, TK, TPCK, TPK, TPACK) and their connectedness within Singaporean teachers (N = 222) by using self-reports. In line with Mishra and Koehler (2006), the authors obtained a seven-factor structure reflecting the different TPACK components.

However, this factorial structure could rarely be demonstrated by other studies (see Archambault & Barnett, 2010; Koh, Woo, & Lim, 2013; Scherer et al., 2018). The mixed findings regarding the factorial structure of TPACK could be attributed to the use of self-report measures for assessing teachers' professional knowledge. Whereas for specific knowledge components, such as technological knowledge (TK), self-reports have been demonstrated to be valid indicators of teacher knowledge, for complex and integrated knowledge structures (e.g., technological pedagogical knowledge), self-assessments become more error-prone, resulting in biased estimates of teacher knowledge (Akyuz, 2018; Hargittai, 2005; Kopcha et al., 2014; Scherer et al., 2018). Interestingly, self-assessments of skills and knowledge are recently discussed to rather capture teachers' current beliefs in their capability to achieve technology integration (i.e., self-efficacy, see Bandura, 1982; Marsh et al., 2019) than their actual state of knowledge (see also Chai et al., 2016; Graham, 2011; Lachner et al., 2019a; Scherer et al., 2017, for a critical discussion on TPACK self-reports) and may reflect motivational orientations towards technology integration.

Teachers' motivation to use technology

Motivation is conceptualized as an internal state which activates and guides (teaching) behavior (see Green, 2002; Lauermann, Eccles, & Pekrun, 2017). Besides other critical motivational variables, such as teaching enthusiam (Keller, Hoy, Goetz, & Frenzel, 2016; Kunter et al., 2008; Lazarides, Gaspard, & Dicke, 2019) or goal orientation (Butler, 2007; Han, Yin, & Wang, 2016; Retelsdorf, Butler, Streblow, & Schiefele, 2010), a common motivational theory which has been considered frequently in teacher education is the expectancy-value theory (e.g., Hwang et al., 2018; Kale, 2018; Watt & Richardson, 2014). The theory assumes that (teaching) behavior is mostly constrained by self-efficacy beliefs (i.e., individual expectancy to successfully accomplish a task), and the general values which are associated with the task (e.g., utility value of the task, see Eccles & Wigfield, 2002). Regarding teachers' technology integration, specific models were developed and empirically tested which frame the integration of technology (c.f. acceptance of technology) as a function of their self-efficacy when using technology (i.e., TPACK self-efficacy, see Scherer et al., 2018) and their anticipated utility of technologies (e.g., Petko, 2012; Scherer et al., 2019; van Braak et al., 2004). Scherer et al. (2019) conducted a meta-analytic structural equation modeling study comprising 114 empirical studies to investigate the potential effects of teachers' motivational beliefs (i.e., self-efficacy, utility value) on the intention to use technology and their reported technology use. The authors found that teachers' combined motivational beliefs of self-efficacy and utility value largely ($\beta = 0.334$) predicted their intention to use technology when teaching. Higher levels of intentions subsequently resulted in more frequent technology integration ($\beta = 0.296$, see also Wozney et al., 2006, for related studies).

5.2.2 The present study

Study overview

Taken together, previous research generated valuable insights into teachers' professional competences regarding the use of educational technology. At the same time, it has tended to produce relatively mixed findings. The reasons for these mixed findings may be threefold. First, previous research predominantly relied on self-reports for assessing teachers' professional knowledge, which have been shown to be less reliable and less valid measures for assessing the complex and integrated knowledge structures required for teaching with technology (e.g., Akyuz, 2018; Kopcha et al., 2014; Scherer et al., 2017). Second, research often focused on the effects of teachers' professional knowledge or motivational beliefs in an isolated manner (see Kunter et al., 2013 for a critical discussion). Thus, it is not clear whether and how cognitive and motivational factors, as crucial constituents of teachers' professional competence, may interact and differently contribute to the capability to integrate technology for teaching. Third, research often relied on simply assessing the mere quantity of technology use as a primary outcome. Although these findings provide evidence on the general use of technology in classrooms, these studies do not allow investigating the *quality of technology integration* (see Scherer et al., 2019; Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013, for a critical consideration). Therefore, it is important to examine, whether and how educational technology can be used to improve the general *instructional quality* of teaching, for instance by providing challenging learning activities (i.e., cognitive activation), or by supporting students' learning (i.e., instructional support) through individual monitoring and scaffolding of students' learning processes (Fauth et al., 2014; Hugener et al., 2009; Kunter et al., 2013). Furthermore, from an educational technology perspective, it is also important to examine which technologies are utilized by teachers as a proxy for their subject specific use of technologies (i.e., *quantity of technology exploitation*), as well as their capabilities to exploit the distinct functions of the applied educational technologies (i.e., *quality of technology exploitation*) to adequately integrate technology in the classroom (Hamilton et al., 2016; Hughes et al., 2006; Puentedura, 2006).

Against this background, in the current study, we investigated effects of teachers' professional knowledge and their motivational beliefs on their ability to integrate technology to foster the quality of lesson plans (i.e., instructional quality and technology exploitation). To obtain sufficient variability in teachers' professional knowledge and their motivational beliefs, we followed a relative teacher expertise approach (see Borko & Livingston, 1989; Cortina et al., 2015; Herppich et al., 2014; Krauss et al., 2008; Leinhardt & Greeno, 1986; Wolff et al., 2016, for related approaches) and contrasted mathematics teachers who differed in their level of relative expertise. Thus, we selected distinct expertise status groups which clearly differed regarding their academic qualification (pre-service teachers: no state examination, trainee teachers: first state examination, in-service teachers: second state examination), and their teaching experience (no teaching experience, first teaching experience, considerable teaching experience). Therefore, we did not compare trends within a distinct teacher population (e.g., Klassen & Chiu, 2011; Lauermann & König, 2016), but gradual relative expertise differences across different status groups.

In the current study, we first assessed teachers' motivational beliefs (i.e., self-efficacy beliefs and utility value regarding technologies in school) and their basic components of professional knowledge of TPACK (i.e., content knowledge and pedagogical content knowledge with a test-based assessment, and technological knowledge with a self-report questionnaire). Subsequently, we provided the teachers with a lesson-planning scenario to investigate their reasoning when designing technology-enhanced mathematics lessons. In this scenario, the teachers were asked to design a lesson plan to introduce the Pythagorean theorem to a secondary mathematics class. By means of content analysis, we rated the quality of the lesson plans regarding the instructional quality (Fauth et al., 2014; Hugener et al., 2009; Kunter et al., 2013; Praetorius et al., 2014) and the technology exploitation (Hamilton et al., 2016; Hughes et al., 2006; Puentedura, 2006).

Research Questions and Hypotheses

Hypotheses 1: Teachers' professional knowledge. Following the relative expert-novice paradigm (e.g., Berliner, 2001; Chi, 2011; Wolff et al., 2017), we hypothesized that advanced teachers (i.e., trainee teachers, in-service teachers) would possess more content knowledge (H1a) and pedagogical content knowledge (H1b) than novice teachers (i.e., pre-service teachers). Additionally, we expected that in-service teachers possessed more content knowledge and pedagogical content knowledge than trainee teachers due to their higher levels of relative teacher expertise. Furthermore, we explored expertise-related differences regarding teachers' self-reported technological knowledge (H1c). However, we refrained from making clear predictions, as technological subject-matter is commonly not (yet) an obligatory part of the curriculum in German teacher education programs, and is mainly acquired from informal learning processes.

Hypotheses 2: Teachers' motivational beliefs. We explored teachers' motivational beliefs as a further constituent of their professional competence. Following expectancy-value theory (Eccles & Wigfield, 2002), we explored potential expertise-related differences regarding teachers' self-efficacy beliefs in teaching mathematics with technology (i.e., TPACK self-efficacy; H2a) and their perceived utility of using technology for teaching (i.e., utility value; H2b).

Hypotheses 3: Quality of the lesson plans. Finally, we investigated the effects of teachers' expertise on the quality of technology-enhanced lesson plans, measured by the *instructional quality* (H3a) and the *technology exploitation* (H3b) of the lesson plans. We hypothesized that advanced teachers (i.e., trainee teachers, in-service teachers) would provide better lesson plans in terms of instructional quality and technology exploitation than novice teachers (i.e., pre-service teachers), whereas in-service teachers would also provide better lesson plans than trainee teachers.

Hypotheses 4: Mediating processes. Additionally, we explored whether teachers' professional knowledge (i.e., content knowledge, pedagogical content knowledge, technological knowledge) and/or teachers' motivational beliefs (i.e., TPACK self-efficacy, utility value) mediated the assumed effects of their relative expertise on the *instructional quality* (H4a) and the *quality of technology exploitation* (H4b) of the lesson plans. This analysis allowed us to disentangle whether the effects of teachers' relative expertise occurred because of differences regarding their cognitive and motivational constituents of their professional competence (i.e., professional knowledge, motivational beliefs).

6.2 Method

6.2.1 Participants and design

Ninety-four German mathematics teachers (academic track) differing in their level of relative teacher expertise (i.e., pre-service teachers, trainee teachers, in-service teachers) participated in the study. We excluded one trainee teacher and one in-service teacher from the analysis as they did not complete the study. Thus, the final sample comprised of 92 mathematics teachers (63 female). The size of the recruited sample exceeded the required sample size as determined by an a-priori power analysis (G*Power: Faul, Erdfelder, Buchner, & Lang, 2009). The required sample size was $N = 69$ when setting α-error to .05 and power to .80. We assumed a medium to large effect regarding potential differences between expert and novice teachers ($\eta_p^2 = .13$). A medium to large effect can be expected as recent teacher expertise studies showed medium to large effects of teacher's relative expertise both on the availability of professional knowledge (König & Lebens, 2012; Krauss et al., 2008) and on the quality of related but distinct core practices, such as the generation of instruction and lesson plans (Lachner & Nückles, 2016; Leinhardt, 1989), classroom monitoring (e.g., Cortina et al., 2015; König & Lebens, 2012; Wolff et al., 2017; Wolff et al., 2016), or formative assessment (Herppich et al., 2014).

The pre-service teachers ($n = 28$) were undergraduate students with a major in mathematics teaching. They were in their fourth semester on average and had no teaching experience. The trainee teachers ($n = 42$) held the first sate examination of the teacher education program and were enrolled in the specialized induction program for the German academic track (Gymnasium). They had on average half a year of teaching experience ($SD = 0.52$). The in-service teachers ($n = 22$) had successfully completed the teacher education program (i.e., university program and the induction program and therefore held the second state examination). They possessed considerable teaching experience ($M = 14$ years, $SD = 11.20$).

The study had a three-group, one-factorial design, with the independent categorial variable *teacher's relative expertise* (i.e., pre-service teachers, trainee teachers, in-service teachers) and the dependent variables *instructional quality* and *technology exploitation* of the lesson plans. As mediating variables, we assessed teachers' professional knowledge (i.e., content knowledge, pedagogical content knowledge, and self-report technological knowledge), and their motivational beliefs (i.e., TPACK self-efficacy, utility value), as constituting parts of their professional competence.

6.2.2 Materials

Teachers' professional knowledge

We assessed teachers' professional knowledge with three different subtests.

Content knowledge. To assess teachers' in-depth content knowledge about the Pythagorean theorem (which was the topic of the provided scenario), two subject-matter experts developed a content knowledge test. The test comprised of 12 multiple-response items with four answer options (for examples, see Appendix). The reliability of the content knowledge test was satisfying (Cronbach's $\alpha = .63$), given that we assessed different scientific aspects of the Pythagorean theorem.

Pedagogical content knowledge. To assess specific pedagogical content knowledge regarding the Pythagorean theorem, we administered two open questions which related to teachers' professional knowledge about students' problems and misconceptions (i.e., "Which difficulties do students generally encounter while learning the Pythagorean theorem?"; "Which misconceptions do students generally possess regarding the Pythagorean theorem?"). Answers were scored with a coding scheme (i.e., task-specific and general conceptual misconceptions, procedural difficulties, and pedagogical justification of the answer), yielding a possible maximum score of 8 (see also Krauss et al., 2008; Voss et al., 2011, for related approaches). To measure the reliability of our PCK-test, we followed suggestions by Chi (1997) and asked two trained raters to code 20% of the participants' answers. Interrater agreement (two-way random effects, absolute agreement, single measurement) was very good, *ICC* (2,1) = .85 (Koo & Li, 2016; Wirtz & Caspar, 2002). Thus, only one rater coded the remaining answers (see also Herppich et al., 2014; Kant, Scheiter, & Oschatz, 2017; Lachner, Backfisch, Hoogerheide, van

Gog, & Renkl, 2019; Schmidgall, Eitel, & Scheiter, 2019; Willoughby, Anderson, Wood, Mueller, & Ross, 2009, for related approaches).[3]

Technological knowledge. We used a self-report measure for assessing technological knowledge, as recent empirical research documented the validity of self-report measures regarding specific technological knowledge (Akyuz, 2018; Hargittai, 2005). We adapted the test by Hargittai and presented current and available technologies which are frequently used in technology-enhanced mathematics instruction (i.e., software, hardware, actions with technology). The teachers were required to assess their availability of knowledge regarding these technologies. The test comprised of eight items (e.g., “I can install apps on tablets.”; “I can design interactive exercises for students with GeoGebra.”). Teachers answered the questions on a five-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*). To analyze the quality of the adapted questionnaire, as part of the current main study, we conducted an online pre-study with $N = 69$ mathematics teachers ($n = 57$ pre-service teachers and $n = 12$ trainee teachers) who were asked to answer the technological knowledge questionnaire. None of the mathematics teachers of the pre-study participated in the main study. Although Cronbach’s alpha was good (pre-study: Cronbach’s $\alpha = .81$; main study: Cronbach’s $\alpha = .76$), confirmatory factor analyses with the sample of the pre-study revealed that the presumed one-factorial structure of the technological knowledge questionnaire was not met, as the model fit indices fell below the conventional cutoff criteria ($CFI = .827$, $SRMR = .089$, $RMSEA = .148$, Hu & Bentler, 1999). The poor model fit indices predominantly resulted from the low factor loadings of three items (model fit without these items: $CFI = 1.00$, $SRMR = .039$, $RMSEA < .001$). However, we decided to include these three items in one index as excluding the items would lead to lower Cronbach’s alpha which might suggest that the results of the confirmatory factor analysis should treated with caution (potentially due to the restricted sample size). More important, the predictive validity of the group affiliation was higher for the index with the inclusion of the three items ($r^2 = .29$), than with exclusion of the three items ($r^2 = .12$) and including or excluding the items did not change the main findings. Additionally, from a conceptual point of view the three items covered crucial aspects of technology-enhanced teaching (e.g., “I can design interactive exercises for students with GeoGebra.”).

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[3] Additionally, we measured teachers’ general pedagogical content knowledge by administering some sample items of the PCK-test by Krauss et al. (2008). The reliability of the selected sample items, however, was not satisfying. Therefore, we refrained from reporting these findings.

Motivational beliefs

Following expectancy-value theory (Eccles & Wigfield, 2002), we measured teachers' self-efficacy beliefs of teaching mathematics with technologies and their perceived utility value regarding technology-enhanced teaching of mathematics.

TPACK self-efficacy. To assess teachers' self-efficacy beliefs regarding the domain-specific integration of technology during mathematics teaching (i.e., TPACK-self efficacy, see Scherer et al., 2018), we used the questionnaire by Schmidt et al. (2009) comprising of seven items which were translated into German. With the help of these items, teachers had to prospectively assess whether they would be capable of applying distinct educational technologies to advance mathematical learning and teaching processes (e.g., "I can use educational technology to increase the learning success of the students"; "I can use educational technology to optimize the methods in my lesson."; Cronbach's $\alpha = .90$). The items were answered on a five-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

Utility value of educational technology. Regarding teachers' perceived utility value of educational technologies, we applied a scale by van Braak et al. (2004) comprising of four items (e.g., "I believe that a progressive introduction of technology into education responds to our society's changing needs"; "I highly value the introduction of technology in the classroom.", see also Sang et al., 2010; Teo et al., 2018; Cronbach's $\alpha = .83$). Again, the items were answered on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Lesson plan scenario

To analyze teachers' capability of integrating technology, we followed a scenario approach in which teachers were required to design a lesson plan and select educational technologies for distinct teaching processes. This procedure allowed us to measure their ability to adequately choose educational technology for potential teaching processes in a contextualized but also highly controlled manner (see also Harris & Hofer, 2011; Kopcha et al., 2014; Kramarski & Michalsky, 2010 for similar approaches). The use of lesson plans was further motivated by the fact that in many educational systems the provision of lesson plans, and the selection of distinct educational technologies is a common core practice in teaching (Bos et al., 2014). The teachers were given the following scenario (see also, Lachner, Weinhuber, & Nückles, 2019b; Ostermann, Leuders, & Nückles, 2015, for related scenarios in mathematics):

> In your school, students and teachers were recently equipped with tablets. You are asked to integrate tablets in your mathematics classes (8th grade). Your class comprises of 30 students with different levels of mathematics achievement. The individual achievement levels are comparably distributed among the class (i.e., there are equally as many high-performing, medium-performing, and low-performing students). In the next lesson (45 minutes), you will introduce the Pythagorean theorem to your class. Please design a lesson plan for this lesson in the provided spreadsheet. You are free in selecting the instructional method. However, you are required to integrate tablets when teaching. The extent and duration of the tablet use is left to you.

The scenario can be regarded to be authentic considering that due to recent political initiatives, schools are increasingly equipped with educational technologies such as tablets. Furthermore, German teachers are exclusively responsible for selecting learning materials and educational technologies and - if they see fit for their lesson - to implement them accordingly. However, currently they receive little if any support in developing technology-enhanced lessons.

Similar to commonly applied templates in teacher education, the teachers filled out a provided spreadsheet comprising three main columns (i.e., learning objectives, social form, and technology use). To further enhance teachers' processing, we included a set of prompts (e.g., "What are your learning objectives of the different lesson sequences?", "How do you want to work on these objectives with your students in the different sequences?", "How do you want to integrate tablets in the different sequences?" see Kramarski & Michalsky, 2010, for related approaches).

We analyzed the quality of the lesson plans on two different dimensions: a) instructional quality (as measured by ratings of cognitive activation and instructional support) and b) technology exploitation (as measured by the quantity of technology exploitation as types of usage and quality of technology exploitation as the level of potential exploitation).

Instructional quality. Instructional quality was assessed by the quality of the described teaching methods within the lesson plans in terms of potential cognitive activation and instructional support (Hardy et al., 2006; Hugener et al., 2009). Thus, instructional quality assessed the potential quality of teaching methods which could be achieved by realizing the lesson plans. To measure instructional quality, we used an adapted coding scheme by Hugener et al. (2009) and rated the lesson plans by means of seven criteria (i.e., provision of cognitive challenging activities, activation of prior knowledge, initiating of conceptual change, engaging students' self-explanations, support of students' self-discovery, provision of guidance, provision of prompts/feedback, for examples, see Table 3). For each category, the teachers could receive 0 (subcategory not present) to 3 points (subcategory completely present) on a three-point Likert scale, yielding a possible maximum score of 21. Two raters coded 20% of the lesson plans, *ICC* (2,1) = .84 to ensure the reusability and clarity of the categorization scheme.

Table 3

Coding Scheme of Instructional Quality

Subcategories	Description	Prototypical example of high quality
Provision of cognitive challenging activities	Teacher provided students with challenging tasks.	Students evaluate the relationship of the three different side squares of triangles.
Activation of prior knowledge	Teacher provided tasks to activate students' prior knowledge.	Students are required to recall the different kinds of triangles at the beginning of a lesson by an assessment app.
Initiating conceptual change	Teacher addressed students' potential misconceptions.	Students work with an app where triangles can be changed dynamically. On the triangle sides (e.g., a) hang squares which display squares with the side length of the triangle side lengths (e.g., a^2). With that students get a conceptual understanding of the meaning of the squared triangles side lengths within the theorem.
Engaging students' self-explanations	Teacher asked students to self-explain information.	Teacher shows not right-angled and right-angled triangles with the tablet. Students have to explain whether the Pythagorean theorem also applies here.
Support of students' self-discovery	Students have to discover underlying concepts.	Dyads of students receive a problem in which they apply the Pythagorean theorem.
Provision of guidance	Teacher gives guidance.	Teacher distributes prepared worksheets with step-by-step worked examples.
Provision of prompts/feedback	Teacher provides feedback to a student's answer.	Teacher provides in-time feedback during the problem-solving phase.

Technology exploitation. First, we examined the quantity of technology exploitation by analyzing the different types of educational technologies which the teachers described in their lesson plans, as a proxy for the use of innovative educational technologies. As simply counting the different types of technologies would result in a plethora of different technologies, we aggregated the different technologies by means of an inductive categorization procedure (Mayring, 2015), which resulted in seven dominant types of educational technologies: presentation applications, dynamic geometry environments, file transfer services, media players, audience response systems, and web search engines. Inter-rater agreement of two raters coding 20% of the lesson plans was good with 89 % of total agreement (*Kappa* = .717).

More importantly, we analyzed the quality of technology exploitation within the lesson plans, which allowed us to assess whether teachers were able to exploit the distinct functions of technologies to potentially support students' learning processes (Hughes et al., 2006; Puentedura, 2006). Based on conceptualizations by Puentedura (2006), the quality of technology exploitation was assessed on four hierarchical dimensions: substitution, augmentation, modification, and redefinition (see Table 4, for the coding scheme). As such, participants could receive 0 (i.e., no technology integration) to 4 (i.e., technology-use which redefined teaching processes) points for the entire lesson plan (see Table 4, for examples). Again 20 % of the lesson plans were rated by two coders. Interrater reliability was very good, *ICC* (2,1) = .90.

6.2.1 Procedure

The entire study was tablet-based and lasted 90 minutes. The teachers were tested in small groups and were each seated in front of a tablet computer (Apple iPad 4) and a wireless keyboard. At the beginning, the experimenter informed the teachers about the main scope of the study and obtained written consent. In the introduction phase (15 minutes), the teachers answered the two motivation scales (i.e., TPACK self-efficacy, utility value of educational technologies). In the knowledge assessment phase (30 minutes), they completed the two knowledge tests (i.e., content knowledge test, pedagogical content knowledge test) and indicated their technological knowledge with the self-report questionnaire. In the planning phase (40 minutes), the teachers designed a lesson plan to assess their situational knowledge about integrating technology in mathematics instruction. At the end of the study, the teachers answered a short demographic questionnaire (e.g., gender, teaching experience, vocational training). After completing the study, all teachers were debriefed.

Table 4

Coding Scheme of Quality of Technology Exploitation

Criteria[a]	Description	Prototypical examples
Substitution	The technology substitutes traditional media with no functional enrichment.	Students read a scanned text.
Augmentation	The technology substitutes with functional enrichment.	Students read a text which is enriched with hyperlinks, so that students can retrieve additional information if needed.
Modification	The technology enables a significantly redesign of a task.	Students use geometry apps to scaffold their conceptual understanding of the Pythagorean theorem.
Redefinition	The technology allows novel learning tasks, which would not be possible without using technology.	Students create an e-book with interactive materials such as simulations and audio explanations about the Pythagorean theorem.

[a]The criteria are hierarchical, resulting in 1 point (*substitution*) to 4 points (*redefinition*) for each lesson plan based on the highest dimension applied within the respective lesson plan.

6.3 Results

We applied an alpha level of .05 for all statistical analyses. We used partial η^2 (η_p^2) as an effect size measure, interpreting values < .06 as a small effect, values between .06 and .14 as a medium effect, and values > .14 as a large effect (see Cohen, 1988).

6.3.1 Preliminary analyses

Several ANOVAs and χ^2 - tests revealed no significant differences between the expertise groups regarding gender $\chi^2(2) = 4.56$, $p = .102$; their possession of a private tablet, $\chi^2(2) = 3.90$, $p = .142$; and their instructional beliefs, $F(2, 89) = 0.62$, $p = .537$, $\eta_p^2 = .014$. Furthermore, the advanced teachers (i.e., trainee teachers and in-service teachers) were comparable regarding their amount of vocational training concerning the implementation of technology, $\chi^2(63) = 4.23$, $p = .238$; and regarding their average use of technology when teaching $\chi^2(63) = 0.34$, $p = .555$. Naturally, the three expertise groups differed regarding their teaching experience, $F(2, 89) = 54.93$, $p < .001$, $\eta_p^2 = .555$. For the descriptive statistics, see Table 5.

Table 5

Descriptive Statistics of Teachers' Demographics

Demographics	Pre-service teachers	Trainee teachers	In-service teachers
Female	75.00 %	61.90 %	45.50 %
Own a private tablet	64.40 %	42.90 %	68.20%
Instructional beliefs[a]	4.21 (SD = 0.43)	4.08 (SD =0.41)	4.09 (SD = 0.67)
Qualification	No university degree	University degree in teacher education (1st state examination)	Certificate by the government to be allowed to teach at schools (2nd state examination)
Teaching experience	None	6 months (SD = 0.52)	14 years (SD = 11.20)
Vocational training regarding teaching with technologies	NA	31.00 %	36.40 %
Taught with technologies more than 3 hours in last half of a year	NA	47.60%	68.20 %

[a] Beliefs about the value of discursive meaningful learning measured with 12 items (e.g., "Teachers should encourage students to find their own solutions to mathematical problems, even if they are inefficient") on a 5-point-Likert Scale from 1 (*strongly disagree*) to 5 (*strongly agree*), Cronbach's α = .84 (applied and validated by Kunter et al., 2013).

Before testing our main hypotheses, as a further safeguard, we checked whether our data were confounded by potential outliers. Graphical boxplot analyses of the dependent variables revealed that there were two outliers (see Figure 9). Both outliers were included in the main analyses, as removing these two participants from the sample did not change the findings.

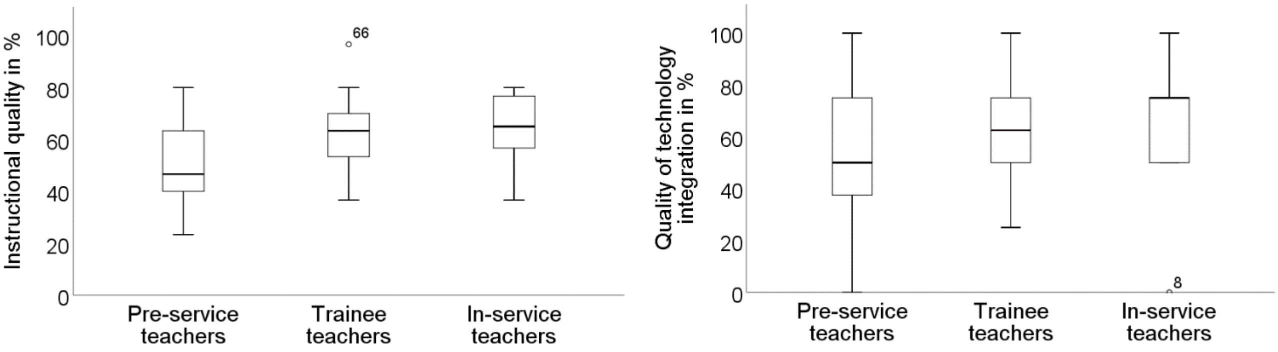

Figure 9. Outlier Analysis with Boxplot Graphics.

6.3.2 *Hypotheses 1*: Teachers’ professional knowledge

By applying contrast analysis (Furr & Rosenthal, 2003), we first tested whether advanced teachers (i.e., trainee teachers and in-service teachers) possessed more professional knowledge (CK, PCK) than novice teachers (i.e., pre-service teachers): pre-service teachers: -2; trainee teachers: 1; in-service teachers: 1 (*expert-novice-contrast*). The second contrast tested for additional differences within the advanced teacher sample (*within-expertise-contrast*: pre-service teachers: 0; trainee teachers: -1; in-service teachers: 1). Regarding teachers’ content knowledge (H1a), the expert-novice-contrast was significant, $F(1, 89) = 5.91$, $p = .017$, $\eta_p^2 = .062$ (medium effect), indicating that trainee teachers and in-service teachers possessed more content knowledge than pre-service teachers. The within-expertise-contrast, however, was not significant, $F(1, 89) = 3.32$, $p = .721$, $\eta_p^2 = .001$ (small effect), suggesting that trainee teachers and in-service teachers possessed comparable amounts of content knowledge. Regarding teachers’ pedagogical content knowledge (H1b), a similar pattern emerged: The expert-novice-contrast was significant, $F(1, 89) = 33.97$, $p < .001$, $\eta_p^2 = .276$ (large effect). Again, the within-expertise-contrast was not significant, $F(1, 89) = 2.44$, $p = .122$, $\eta_p^2 = .027$ (small effect), indicating that advanced teachers (trainee teachers, in-service teachers) outperformed novice teachers (pre-service teachers). There were no significant differences between trainee teachers and in-service teachers (see Table 6). Furthermore, we explored for potential differences regarding teachers’ self-reported technological knowledge (H1c). We performed an ANOVA with the self-reported technological knowledge as the dependent variable and the expertise groups as a between-subjects factor. The ANOVA was not significant, indicating that the teachers perceived comparable technological knowledge across the expertise groups, $F(1, 89) = 1.24$, $p = .292$, $\eta_p^2 = .027$ (small effect, see Table 6).

6.3.3 *Hypotheses 2*: Teachers’ motivational beliefs

To explore potential differences regarding teachers’ motivational beliefs, we conducted a MANOVA with their TPACK self-efficacy beliefs (H2a) and perceived utility value of educational technology (H2b) as the dependent variables and the expertise groups as a between-subjects factor. The MANOVA was significant, Wilk's $\Lambda = 0.76$, $F(1, 89) = 6.51$, $p < .001$, $\eta_p^2 = .129$ (medium effect; univariate ANOVAs: TPACK self-efficacy: $F(1, 89) = .93$, $p = .002$, $\eta_p^2 = .135$, utility value: $F(1, 89) = 7.83$, $p < .001$, $\eta_p^2 = .150$, see Table 6). Regarding TPACK self-efficacy, planned contrasts revealed that in-service teachers had higher levels of TPACK self-efficacy beliefs than trainee teachers, *F*(1, 89) = 13.72, $p < .001$, $\eta_p^2 = .134$ (medium effect), none of the other comparisons were significant ($F < 1$).

For teachers' perceived utility value, we found that advanced teachers (trainee teachers, in-service teachers) reported higher levels of utility value than novice teachers, *F*(1, 89) = 9.80, $p = .002$, $\eta_p^2 = .099$ (medium effect). In-service teachers also had higher utility value than the trainee teachers, *F*(1, 89) = 8.67, $p = .004$, $\eta_p^2 = .089$ (medium effect).

6.3.4 *Hypotheses 3*: Quality of lesson plans

To analyze the quality of the lesson plans, we similarly performed separate contrast analyses for instructional quality and integration of technology. Regarding teachers' instructional quality (H3a), the expert-novice-contrast was significant, *F*(1, 89) = 16.70, $p < .001$, $\eta_p^2 = .158$ (large effect, see Table 6), whereas, the within-expertise-contrast was not significant, *F*(1, 89) = 0.68, $p = .411$, $\eta_p^2 = .008$ (small effect, see Table 6), indicating that lesson plans by advanced teachers (i.e., trainee teachers, in-service teachers) demonstrated higher quality of potential instructional quality than the ones by novice teachers (i.e., pre-service teachers). As for the previous analyses, we did not obtain significant differences between the trainee teachers and the in-service teachers.

To investigate hypothesis 3b, that is, whether teachers' relative expertise also accounted for differences regarding the technology exploitation, we first explored the quantity of technology exploitation as the different types of educational technologies which the teachers reported in their lesson plans (see Figure 10). Overall, the teachers tended to most exclusively rely on presentation applications (e.g., PowerPoint, Keynote), as well as dynamic geometry applications (e.g., GeoGebra). Furthermore, they rarely used audience response systems and web search engines for their lesson, which seems plausible, as we required the teachers to plan an introductory lesson to the Pythagorean theorem. Additionally, the descriptive statistics indicated that advanced teachers (i.e., trainee and in-service teachers) described the use of dynamic geometry applications more often in their planning than novice teachers (i.e., pre-service teachers). Further χ^2-tests with teachers' relative expertise as the independent variable and the frequency of dynamic geometry applications as the dependent variable confirmed this assumption, $\chi^2(2) = 10.89$, $p = .004$, $\eta_p^2 = .118$ (large effect).

Table 6

Means and Standard Deviations of the Dependent Measures as a Function of Teachers' Relative Expertise

Variables	Pre-service teachers		Trainee teachers		In-service teachers	
	M	*SD*	*M*	*SD*	*M*	*SD*
Professional knowledge[a]						
Content knowledge	75.52	7.70	79.97	9.87	81.75	6.11
Pedagogical content knowledge	34.23	10.23	57.32	23.44	65.08	22.92
Technological knowledge	42.85	12.98	46.11	13.32	42.99	15.87
Motivational beliefs[b]						
Utility-value	2.71	0.91	2.98	.73	3.63	0.89
Self-efficacy beliefs	3.06	1.03	2.66	.85	3.56	0.89
Quality of lesson plans[a]						
Instructional quality	50.83	14.81	61.58	12.12	64.39	11.74
Quality of technology exploitation	50.89	24.98	63.09	19.31	64.77	21.35

[a] Values represent percentage scores.
[b] Teacher ratings ranged from 1 (*strongly disagree*) to 5 (*strongly agree*).

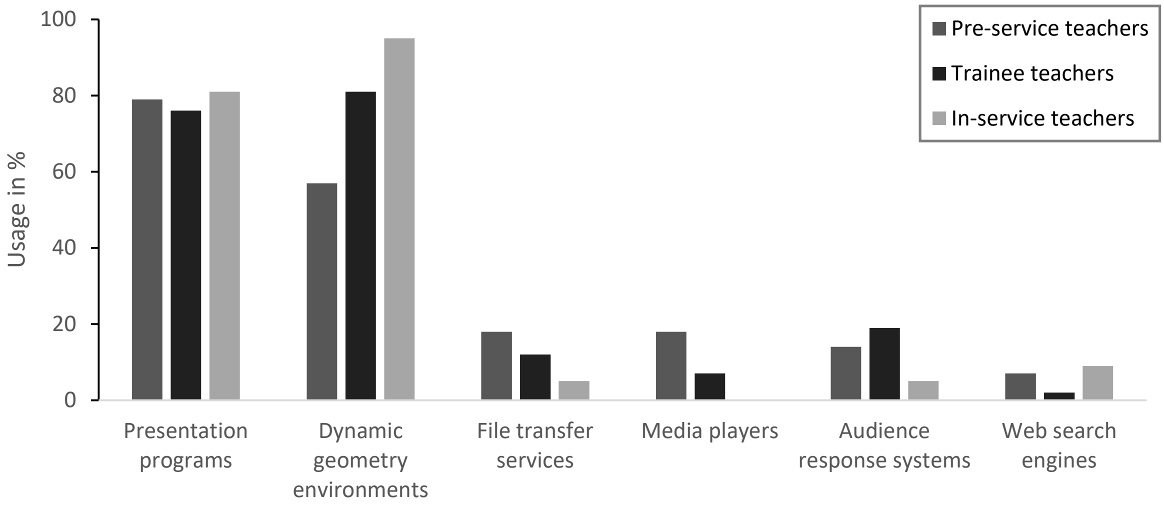

Figure 10. Type of mentioned Technologies within the Lesson Plans. Bar Charts represent the Frequency of Use of the different Applications per relative Expertise Group.

More importantly, we analyzed the quality of teachers' technology exploitation of the distinct technologies. Therefore, we conducted separate contrast analyses with the technology exploitation as the dependent variable. Again, we found that the expert-novice-contrast was significant, $F(1, 89) = 6.84$, $p = .011$, $\eta_p^2 = .071$ (medium effect). The within-expertise-contrast was not significant, $F(1, 89) = .09$, $p = .769$, $\eta_p^2 = .001$ (small effect), indicating that advanced teachers (i.e., trainee teachers and in-service teachers) outperformed novice teachers (i.e., pre-service teachers) regarding the quality of technology exploitation. Again, there were no significant differences between the advanced teachers (i.e., trainee teachers, in-service teachers).

6.3.5 *Hypothesis 4*: The mediating processes

Finally, we examined the underlying processes of the effects of teachers' relative expertise on the quality of lesson plans (H4). First, we conducted simple univariate correlations between the dependent measures (i.e., instructional quality, quality of technology exploitation) and teachers' professional knowledge (CK, PCK, TK) and motivational beliefs (i.e., TPACK self-efficacy, utility value), as indicators of their professional competence. The correlations revealed that instructional quality was significantly correlated with teachers' pedagogical content knowledge and their perceived utility value (see Table 7). The quality of technology exploitation was significantly correlated with teachers' pedagogical content knowledge, the perceived utility value of educational technologies, and their TPACK self-efficacy beliefs (see Table 7).

Table 7

Bivariate Correlations among the Dependent Measures

	1	2	3	4	5	6
1 Instructional quality						
2 Quality of technology exploitation	.577**					
3 Content knowledge	.094	.079				
4 Pedagogical content knowledge	.209*	.223*	.284**			
5 Technological knowledge	-.117	.077	.056	.140		
6 Utility-value	.327**	.422**	.134	.218*	.293**	
7 Self-efficacy beliefs	.131	.235*	.006	.079	.704**	.543**

* $p < .05$. ** $p < .001$.

Regarding the underlying effects of instructional quality (H4a), we conducted a mediation analysis with pedagogical content knowledge and utility value as simultaneous mediators (as they were significantly correlated with instructional quality). Teachers' relative expertise was the contrast-coded predictor (pre-service teachers: -2; trainee teachers: 1; in-service teachers: 1) and instructional quality was the dependent variable (see Figure 11). We applied the bootstrapping methodology by Hayes (2017) via the PROCESS macro version 3 for SPSS and ran 10,000 bootstrap samples to derive 95% confidence intervals for the indirect effect (Valente, Gonzalez, Miočević, & MacKinnon, 2016). The mediation analyses revealed that the effect of expertise on instructional quality of the lesson plans was mediated by teachers' perceived utility value $a \times b = .633$, $SE = .367$, 95% CI [.035; 1.457], as zero was not included in the confidence intervals. However, the mediation via teachers' pedagogical content knowledge was not significant, $a \times b = -.069$, $SE = .613$, 95% CI [-1.294; 1.106].

Regarding teachers' quality of technology exploitation, we similarly included teachers' utility value, TPACK self-efficacy beliefs, and pedagogical content knowledge as potential mediators, as all three variables were correlated with the quality of technology exploitation. The analysis revealed that the instructional quality was mediated by teachers' utility value $a \times b = 4.174$, $SE = 2.098$, 95% CI [.776; .8.836], but not by teachers' pedagogical content knowledge $a \times b = 1.847$, $SE = 1.451$, 95% CI [-.902; 4.880], nor by their TPACK self-efficacy beliefs $a \times b = .091$, $SE = .657$, 95% CI [-1.363; 1.416]. Apparently, only the perceived utility accounted for the instructional quality and the quality of technology exploitation of teachers' lesson plans (see Figure 11).

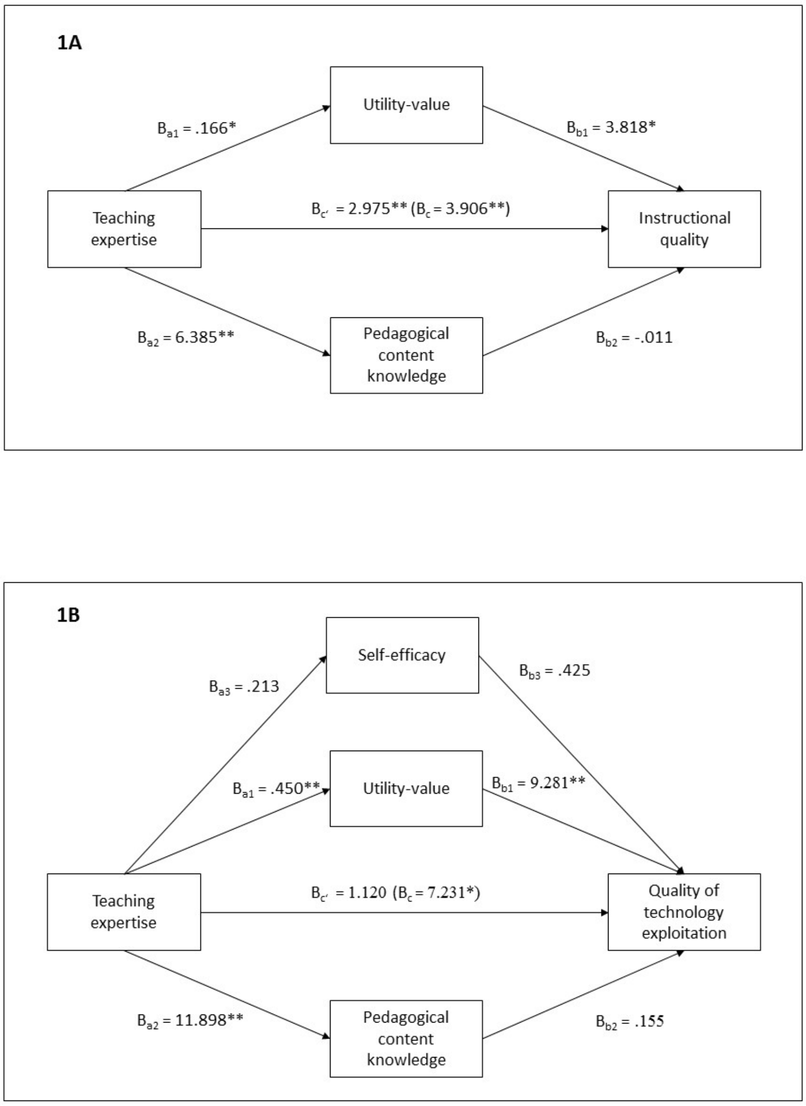

Figure 11. Findings of the -Parallel Mediation Analyses for Instructional Quality (Figure 1A) and Quality of Technology Exploitation (Figure 1B).

Note. Teaching experience coded with the expert-novice-contrast (pre-service teachers = -2, trainee teachers = 1, in-service teachers = 1) as independent variable. Pedagogical knowledge, instructional quality, and quality of technology exploitation were measured by percentage scores. Numbers represent unstandardized path coefficients for direct and total effects (in parentheses). **p* < .05. ***p* < .01.

6.4 Discussion

In the present study, we investigated whether and how teachers' professional knowledge and motivational beliefs - crucial facets of their professional competence - have differential effects on the quality of technology integration within mathematics lesson plans depending on teachers' relative levels of expertise. In line with general findings on relative teacher expertise (Baumert et al., 2010; Berliner, 2004; McIntyre et al., 2017), we found that advanced teachers (i.e., trainee teachers and in-service teachers) designed lesson plans with higher instructional quality and higher levels of technology exploitation than novice teachers (i.e., pre-service teachers). Mediation analyses revealed that the effect of relative teacher expertise was mediated by the perceived utility of technology for teaching. Thus, teachers' perceived utility played a crucial role for designing technology-enhanced mathematics instruction.

From a technological point of view, this finding is interesting. Even though across expertise groups, the teachers described the use of comparable types of technologies (except for dynamic geometry applications) in their lesson plans, the advanced teachers used the technologies differently for teaching and process and exploited the potential of distinct technologies in a more pronounced manner., resulting in higher levels of instructional quality and technology exploitation. Therefore, the higher levels of instructional quality and technology exploitation likely resulted as the advanced teachers used the technologies differently for teaching processes (Ertmer et al., 2012), and exploited the potential of distinct technologies in a more pronounced manner (see Table 8 for prototypical contrasting examples, Teddlie & Yu, 2007).

What are the theoretical merits of our study? First, in line with general findings on teaching quality (e.g., Baumert et al., 2010; Hill et al., 2008; Kunter et al., 2013), the significant correlation between PCK and teaching quality suggests that teachers' pedagogical content knowledge was considerably related to the quality of their lesson plans across expertise groups (see Table 7). Although the self-reported technological knowledge predicted teachers' TPACK self-efficacy (see also Akyuz, 2018, for related findings), it was not related to their ability to integrate technologies in a qualitative manner. This finding suggests that rather subject specific pedagogical content knowledge is relevant to deliberately use technology for teaching, however knowledge about specific technologies (i.e., technological knowledge) seems less important. On one hand, this finding could have resulted as we administered a self-assessment questionnaire for measuring teachers' technological knowledge. On the other hand, our findings were recently replicated in a domain-general setting with test-based assessments. Lachner and colleagues (2019a) asked in-service teachers to answer different knowledge tests. The authors showed that only teachers' pedagogical knowledge predicted the availability of technological pedagogical knowledge, but not their technological knowledge. These findings strengthen the assumption that particularly professional knowledge, which is related to pedagogical (content) knowledge, is relevant to effectively integrate technology during teaching.

Table 8

Prototypical Contrasting Cases of the Lesson Plans of each Expertise Group

	Learning objectives	Technology use
Pre-service teacher	The students should understand the statement of the Pythagorean theorem.	Teachers presents static visualizations of different triangles with the areas of the page squares.
	Students consolidate their knowledge.	Students practice using paper pencil.
Trainee teacher	The students should realize that the Pythagorean theorem is only valid in right-angled triangles by working on everyday tasks.	Students explore the problems with GeoGebra©.
	The different characteristics of triangles is clear to students.	Teacher presents static visualization of triangles.
	Students can formulate the Pythagorean theorem.	Students write on paper.
In-service teacher	The students should understand the relevance of the Pythagorean theorem.	Teacher shows pictures about the problem of equal determination of cornfields in ancient Egypt.
	Students understand underlying concepts of the Pythagorean theorem.	Students get simulations in GeoGebra© with the option to recap prior knowledge if necessary (e.g., right triangles) and the task to explain the relationships of the components of the formula of the Pythagorean theorem.
	Students can explain the meaning of the Pythagorean theorem in their own words.	Some students present their assumptions.
	Students understand relationship of formula and application.	Teacher shows pictures of the beginning again and class applies the Pythagorean theorem together.

Note. These are paraphrased lesson plans to be space-saving.

Second, our mediation analysis confirmed that teachers' motivational conditions largely accounted for effective technology integration. In line with the expectancy-value theory (Eccles & Wigfield, 2002), it seems that teachers' perceived utility value increased their efforts to integrate technology in a didactical manner during the lesson design, which subsequently increased the instructional quality and quality of technology exploitation of the designed lesson plans. An unexpected finding, however, was that TPACK self-efficacy beliefs did not mediate the effect of teacher's relative expertise on instructional quality and technology exploitation, given that previous studies demonstrated distinct relations between teachers' TPACK self-efficacy, and their use of technology (Farjon et al., 2019; Knezek & Christensen, 2016; Petko, 2012). On the one hand, this finding may have resulted from the fact that we required our participants to use technology in the experimental design of the study. However, the non-significant findings were also obtained in studies in which teachers could apply educational technology in an optional manner (see Study 2, Chapter 7). Therefore, we rather attribute these different findings to the fact that we measured the quality and not the quantity of technology integration. Apparently, high levels of self-efficacy may be required to regularly apply technology in classroom settings (i.e., quantity of technology integration), as indicated by research which documented distinct relationships between teachers' technology-related self-efficacy beliefs and their frequency of technology integration (Scherer et al., 2018). Whether and how teachers implement technology deliberately for teaching processes (i.e., the quality of technology integration), however, appears to rather depend on the perceived utility of technology for teaching. These findings are in line with studies inspired by the framework of distributed cognition (Hollan, Hutchins, & Kirsh, 2000), as they highlighted that a sound integration of technology during teaching goes beyond operational knowledge of educational technologies (Ligorio, et al., 2008; Narciss & Koerndle, 2008). That said, process-data by means of think-aloud protocols or interviews, as well as the analysis of actual planning and teaching processes in authentic scenarios in which teachers also have access to the web or teaching platforms, are needed to more directly investigate the underlying processes of technology integration.

Third, from a methodological perspective, our study adds to potential advancements in measuring teachers' technology integration. Previous quantitative research primarily relied on self-report measures which asked teachers to report the frequency of technology use (e.g., Lin et al., 2013; Petko, 2012; Scherer et al., 2019), which often suffer from reliability and validity issues. As a consequence, these self-assessments are often only weakly correlated with teachers' actual performance (Akyuz, 2018; Kopcha et al., 2014). In contrast, we followed a scenario approach in which teachers were required to plan a technology-enhanced lesson (see also Harris & Hofer, 2011; Kramarski & Michalsky, 2010). Additionally, we adapted frequently used and feasible rating schemes from research on instructional quality to measure the quality of the lesson plans (e.g., Hugener et al., 2009; Kunter et al., 2013; Praetorius et al., 2014). Using scenarios allows researchers to measure qualitative aspects of teachers' technology integration as a function of their ability to implement high instructional quality and a high level of technology exploitation in a relatively controlled albeit highly contextualized manner, as teachers were asked to provide potential worked-out plans for a technology-enhanced mathematics lesson. This assumption is also corroborated by findings which documented that scenario approaches may trigger similar cognitive and motivational processes as authentic (teaching) practices (Bolzer, Strijbos, & Fischer, 2015; Robinson & Clore, 2001). However, we have to note that we did not obtain significant differences between the trainee teachers and the in-service teachers, particularly on their knowledge dimensions (i.e., CK, PCK), and on the quality of the lesson plans (i.e., instructional quality, quality of technology exploitation). Based on the current findings only, it is difficult to pinpoint potential reasons for these non-significant differences which may reflect true equalities or potential shortcomings of scenario-based approaches. It is possible that lesson plan scenarios are capable to separate only coarse expertise differences that occur when contrasting pre-service teachers without any teaching experience with trainee or in-service teachers, who both have teaching experience, albeit to different degrees. A scenario approach may be less suited to reveal more fine-grained differences resulting from the amount of practical experience. Therefore, it would be interesting to reinvestigate relative expertise differences more situated in authentic classroom studies in which teachers deliberately integrate technology during teaching (see for related approaches the analysis of videotaped lessons, Hugener et al., 2009). On the other hand, it could also well be that trainee teachers and in-service teachers are comparable in their lesson plan competence as this is a core practice of their daily teaching and extensively trained during the formal teacher education program which both trainee teachers and in-service teachers successfully accomplished. Accordingly, it is an open issue whether professional knowledge primarily develops as a function of formal teacher education or of teaching experience.

Fourth, regarding educational practice, our findings further suggest that teachers' motivational beliefs should be more strongly considered in teacher education. Focusing on the motivational beliefs and their associated experiences may provide a beneficial approach to enhance teachers' professional development (Borko, 2004), for instance by integrating methods of systematic self-reflection in which teachers can monitor their motivational beliefs during technology-enhanced teaching.

6.4.1 Limitations and future research

One limitation refers to the causality of our findings, as we analyzed the quality of authentic lesson plans by different teacher groups that varied in the degree of their relative expertise defined as teaching experience and academic qualification. This approach contributed to the ecological validity of our findings. However, we did not experimentally manipulate the quality of teachers' professional knowledge (i.e., content knowledge, pedagogical content knowledge, technological knowledge) as well as their underlying motivational beliefs (i.e., TPACK self-efficacy, utility value). Therefore, empirical conclusions regarding the causal role of teachers' motivational beliefs for the design of technology-enhanced lesson plans should be treated with caution (Hayes, 2017).

Another caveat is that we only used one single mathematical problem (i.e., the Pythagorean theorem) which possibly restricts the generalizability of our findings. The Pythagorean theorem can be regarded as a representative mathematical problem which is taught throughout secondary education and requires both essential algebraic and geometric knowledge. Nevertheless, it would be worthwhile to replicate our findings with additional mathematical problems and in other domains, particularly in language learning or the humanities, as they require different implementations of educational technology due to different core practices (Mishra & Koehler, 2006).

6.4.2 Conclusion

In conclusion, the present study contributes to a better understanding of teachers' cognitive and motivational conditions which enable them to implement technology in the mathematics classroom. Our findings show that motivational beliefs and especially teachers' perceived utility value of educational technologies play a critical role in integrating technology into teaching. Therefore, motivational aspects should be considered more often in teacher education programs to support teachers to effectively integrate educational technology in their classroom. By effectively integrating educational technologies during teaching, teachers can enhance the quality of their teaching and at the same time help students prepare for a digital future.

7 *Study 2*: A MATTER OF UTILITY!

Variability of Teachers' Technology Integration in the Classroom

The content of the following chapter is currently under review in Computers & Education. The proportional contributions of the different co-authors to the manuscript are presented in the subsequent table. This article may not exactly replicate the final version published in the journal. It is not the copy of record.

Author	Author position	Scientific ideas %	Data generation %	Analysis & interpretation %	Paper writing %
Iris Backfisch	first author	65 %	100 %	75 %	65 %
Andreas Lachner	second author	10 %	0 %	15 %	20 %
Kathleen Stürmer	third author	15 %	0 %	0 %	5 %
Katharina Scheiter	fourth author	10 %	0 %	0 %	10 %

Title of paper:	Variability of teachers' technology integration in the classroom: A matter of utility!
Status:	Under review: *Computers & Education*

Abstract

Technology integration in the classroom is seen as a crucial factor to enhance teaching and learning processes. Whether and how technology affects student learning, depends on how teachers integrate technology into their classroom practice. To investigate technology integration, we used an experience sampling method with in-service teachers (*N* = 18). Over a period of six weeks, we assessed teachers' technology integration and technology-related motivation. By using a mixed-method approach, we found considerable variability of teacher motivation, frequency, and quality of technology integration across lessons. The variability could be explained by teachers' technology-related utility beliefs and specific factors within the different instructional contexts. The findings highlight the importance of teachers' utility and contextual aspects in their technology integration.

7.1 Introduction

Researchers as well as politicians attribute educational technologies to have great potential in contributing to the quality of teaching and thus to the learning of students (Chauhan, 2017; Mayer, 2019; OECD, 2015; Zhu & Urhahne, 2018). However, research shows that teachers tend to rarely use technologies and to exploit only to a limited extent the distinct potential technologies offer (Fraillon, Ainley, Schulz, Friedman, & Duckworth, 2019). A critical boundary condition regarded to constrain technology integration is teacher motivation (see Chapter 6, p. 63, and Petko, 2012; Taimalu & Luik, 2019; Vongkulluksn et al., 2018). Previous research reported positive associations between technology integration and teachers' self-efficacy to use technology in the classroom (e.g., Taimalu & Luik, 2019). Simultaneously, recent studies documented that the anticipated utility of technology for teaching purposes was related to the quantity and quality of technology integration (see Chapter 6, p. 63). However, most previous research was cross-sectional, which has not allowed to investigate the variability and reciprocal relationships between teacher motivation and technology integration. Answering these research questions constitutes an important research avenue, as previous research documented that teacher motivation and teaching quality highly fluctuate across lessons and as such largely depend on the particular instructional context in which technology is applied (Praetorius et al., 2014; Seidel & Prenzel, 2006; Turner & Meyer, 2000).

Against this background, in the current study, we investigated 1) whether and how teacher motivation and technology integration vary across lessons, 2) examined relationships between teacher motivation and quantity and quality of technology integration across lessons, and additionally, 3) explored the contextual factors which affected variations in teacher motivation and technology integration. To investigate these research questions, we conducted an experience sampling study (Endedijk, Brekelmans, Verloop, Sleegers, & Vermunt, 2014), in which we systematically traced trajectories of in-service teacher motivation and the quantity and quality of technology integration over a period of six weeks by means of a web-based teacher-diary. In this teacher-diary, teachers weekly rated their current motivation (i.e., their perceived utility-value and self-efficacy of teaching with technology) and documented one technology-based lesson per week. The resulting data were analyzed by applying a mixed-method approach (McCrudden, Marchand, & Schutz, 2019) aiming at identifying trajectories and reciprocal relations of teacher motivation and the quantity and quality of technology integration. First, quantitative analysis by means of variance component analysis and growth-curve models allowed us to identify potential systematic variations and relations of teacher motivation and technology integration. Second, qualitative analyses by means of criterion-based sampling approaches allowed us to reconstruct potential contextual determinants that affected variability of teacher motivation and technology integration.

7.1.1 Technology integration into classroom practice

Integrating technologies into teaching can be regarded as one of the crucial endeavors to support students' learning and enable them to participate in a digitalized society (OECD, 2015; U.S Department of Education, 2020). In the context of teaching, technology integration commonly refers to teachers' adoption of educational technologies during classroom teaching, such as the use of distinct hardware (e.g., mobile technology, tablets; see Beauchamp et al., 2015), or software applications (e.g., tools, see Krauskopf et al., 2012) to realize specific teaching processes (Danniels et al., 2020; Dukuzumuremyi & Siklander, 2018; Näykki, & Järvelä, 2008; Paratore et al., 2016). Technology integration can be conceptualized on the quantitative and the qualitative level. On the *quantitative* level, technology integration commonly refers to the mere frequency of technology integration, which is, for instance, determined by simply counting how often a particular technology was used during classroom teaching (e.g., Fraillon et al., 2014). These quantity indicators give an overview regarding the general level of technology usage in schools, however, they do not cover in-depth qualitative aspects of technology integration which are presumably crucial for the effectiveness of technology integration (e.g., enhance teaching quality; OECD, 2015).

Following the conceptualization of Study 1 (Chapter 6, p. 63) the *quality* of technology integration can be operationalized on two different dimensions: First, the level of technology exploitation refers to teachers' capability to implement the distinct potential of educational technologies to scaffold students' learning (Endberg, 2019; Hamilton et al., 2016). The most prominent models describing different hierarchical levels of technology exploitation are the SAMR-model (acronym for substitution, augmentation, modification, redefinition, see Puentedura, 2006) and the RAT-model (acronym for replacement, amplification, transformation by Hughes et al., 2006). Both models comprise distinct levels of technology integration: at the lowest level, technologies are used to substitute or replace traditional technologies (e.g., reading a digital pdf document instead of reading a printed book). At the intermediate level, technology integration helps realizing more efficient teaching methods and serves to augment traditional teaching methods (e.g., using a live-synchronized collaborative digital whiteboard). At the highest level, the use of technology may allow teachers to redefine or transform current teaching methods which would not be possible without technology integration, such as providing multi-media information (Moreno & Mayer, 2007; Renkl & Scheiter, 2017) or adaptive support (e.g., Lachner et al., 2019a; Ma, Adesope, Nesbit, & Liu, 2014; Zhu & Urhahne, 2018). Nevertheless, such models only focus on the types of technology use and ignore the potential impact on learning processes (Hamilton et al., 2016) and more precisely the impact on teaching quality (see Chapter 6, p. 63). Although there is a broad range of models conceptualizing teaching quality (Brophy, 1999; Eccles & Roeser, 2009; Hamre & Pianta, 2007; Pianta & Hamre, 2009), there is consensus that teaching quality can be described with respect to the task-specific strategies, which is cognitive activation and individual learning support, and the task-general strategies, such as classroom management (Baumert et al., 2010; Fauth et al., 2014; Hugener et al., 2009; Kunter et al., 2013; Praetorius et al., 2018). *Cognitive activation* refers to task-specific instructional strategies which trigger students' cognitive engagement during learning, for instance, by providing them with challenging tasks, the exploration of concepts, and the activation of prior knowledge. These instructional strategies should contribute to students' deep processing during learning and, in turn, support their content-related understanding (Fauth et al., 2014; Kunter et al., 2013). *Individual learning support* covers instructional strategies which aim at scaffolding task-specific learning processes and knowledge construction (Kunter et al., 2013). Consequently, such support strategies are characterized by forms of student-centered and adaptive teaching (van de Pol, Volman, Oort, & Beishuizen, 2015), such as monitoring students' learning process, providing personalized feedback, and contiguous adaptions of teaching (Kunter et al., 2013; van de Pol et al., 2015). *Classroom management* is a task-general aspect of teaching quality and refers to generic strategies that focus on establishing and maintaining the smoothness of teaching such as coping with potential disruptions during a lesson (Fauth et al., 2014; Kounin, 1970; Kunter et al., 2013). Commonly, it is assumed that technology can have an effect on task-specific aspects of teaching quality (i.e., cognitive activation, individual learning support) because it has the potential to implement demanding learning tasks and cognitively engaging learning environments (e.g., virtual simulations), and at the same time provide students with adequate individual learning support (e.g., adaptive feedback). However, it is an open question whether and how technology integration affects task-general aspects of teaching quality such as the smoothness of the lesson as there is a lack of research in this regard.

7.1.2 Motivation as boundary condition for technology integration

Recent research has identified several boundary conditions that constrain the quantity and quality of technology integration, such as the availability of technological infrastructure (Drossel et al., 2017; Fraillon et al., 2014; Petko, 2012) and the level of teachers' professional knowledge (cf. technological-pedagogical content knowledge, Lachner et al., 2019a; Mishra & Koehler, 2006). More importantly, recent research has emphasized the crucial role of teacher motivation as a further boundary condition of technology integration (see Chapter 6, p. 63 and e.g., Cheng & Xie, 2018; Ifenthaler & Schweinbenz, 2013; Petko, 2012; Scherer et al., 2019; Scherer & Teo, 2019; Taimalu & Luik, 2019; Teo, 2011; Vongkulluksn et al., 2018). For instance, the technology-acceptance model (TAM, see Scherer et al., 2019; Teo, 2011) describes whether and how teachers' acceptance and use of technologies depend on their motivation (see Scherer & Teo, 2019; Teo, 2011).

Scherer et al. (2019) aggregated findings from 114 questionnaire studies (N = 34,577 teachers) which used the TAM as theoretical framework and investigated the relation between teacher motivation (i.e., perceived usefulness of educational technologies, self-efficacy of using educational technologies) and their intention and frequency to use technologies for teaching. The authors found that self-efficacy and perceived usefulness largely predicted teachers' intention to use technology. Moreover, higher levels of behavioral intentions yielded higher degrees of technology integration (see also Scherer & Teo, 2019; Wozney et al., 2006). From a psychological perspective, these findings can be interpreted in terms of expectancy-value theory (Eccles & Wigfield, 2002), which has gained considerable popularity in teacher education in recent years (e.g., Cheng & Xie, 2018; Green, 2002; Wozney et al., 2006). Expectancy-value theories claim that the *successful* realization of a task is largely related to the *individual expectancies* toward successfully accomplishing a certain task (cf. self-efficacy, Bandura, 2010) and the associated *individual value* of the task (cf. utility-value, Eccles & Wigfield, 2002). Furthermore, expectancy-value theories not only consider the *quantity*, but also highlight the *quality* of how teachers successfully accomplish actions as the result of their self-efficacy and perceived utility-value (e.g., expectancy-value theory of achievement-related choices and performance; Eccles & Roeser, 2009, 2011). Therefore, the quality of technology integration during teaching might be influenced by self-efficacy of using technologies for teaching and perceived utility-value of educational technologies for teaching and learning processes. In this context, expectancy-value theory goes beyond specific technology-acceptance models (Teo, 2011), as it also presumes differences in the quality of distinct tasks such as technology integration and not only in the quantity or frequency of technology use.

One of the first studies examining the effects of teacher motivation (i.e., self-efficacy, utility-value) on the *quality* of technology integration is the study presented in Chapter 6. In a relative expertise study, the authors asked teachers to answer a test measuring their professional knowledge and report their self-efficacy and utility-value regarding technology use. Additionally, the participants provided a worked-out lesson plan on the introduction of the Pythagorean theorem. The authors found that teachers with higher levels of expertise (i.e., trainee teachers, in-service teachers) were more capable of integrating technology, as they provided lesson plans involving methods of higher instructional quality and greater technology exploitation than novice teachers. The effect of teacher expertise on the quality of the lesson plans could be explained by the perceived utility-value of technology integration, but not by self-efficacy regarding using technology. Surprisingly, professional knowledge did not mediate the effect of teacher expertise on the quality of technology integration either, indicating that predominantly motivation accounted for the quality of technology integration (Backfisch et al., 2020a).

These findings emphasize the importance of teachers' utility-value regarding their technology integration. Despite the valuable findings, however, it has to be noted that the study in Chapter 6 was cross-sectional and conducted in a controlled but relatively artificial setting, as it only described teachers' potential technology integration by means of a scenario approach regarding one teaching task at one point in time. Thus, it is unclear whether the findings of the study in Chapter 6 would replicate in more applied settings in which teachers were required to actually implement technology over a course of various lessons.

7.1.3 Variability of technology integration and motivation across lessons

There is considerable empirical evidence that the quality of (technology-based) lessons substantially varies across different teachers, but also across individual teachers' lessons (Praetorius et al., 2014; Seidel & Prenzel, 2006). Praetorius et al. (2014) investigated the stability of teaching quality across lessons. By applying variance component analysis, the authors were able to identify stable and varying components of teaching quality measured by observer ratings. Whereas classroom management and individual learning support remained relatively stable across lessons, cognitive activation varied largely across lessons. This variability across lessons indicates that teaching quality is constrained by different instructional contexts. Instructional context encompasses all factors which affect the processes in the classroom (Turner & Meyer, 2000) such as differences in subject-matter content which potentially affect the teaching methods used (see Fauth et al., 2019; Praetorius et al., 2014) but also different levels of teacher and student motivation which potentially influence the smoothness of the lesson and learning outcome of students (Kunter et al., 2013).

This assumption is in line with recent motivational theories (Eccles, 2005; Hidi & Harackiewicz, 2000), which highlight that motivational beliefs depend on distinct aspects of the task to be accomplished and contextual aspects determining the distinct tasks. Therefore, teacher motivation might vary across lessons (Holzberger, Philipp, & Kunter, 2013; Praetorius et al., 2017).

7.1.4 The present study

We aimed at investigating potential relations of teachers' motivation (i.e., self-efficacy, utility-value) and the quantity and quality of technology integration across lessons. Therefore, we followed an experience sampling approach in which teachers regularly wrote entries in a web-based teacher-diary over a period of six weeks (for related approaches see Wäschle, Allgaier, Lachner, Fink, & Nückles, 2014). In each entry, teachers documented their lessons and reported their current self-efficacy and perceived utility-value regarding technology integration. Such experience sampling approaches are often applied within professional settings, like medicine or teacher education, as they do not interfere with daily professional practices (e.g., teaching), and as such, have been shown to be valid instruments to trace trajectories of professional behaviour and its underlying inter-individual constituents (e.g., Endedijk et al., 2014; Könings et al., 2016; Wäschle et al., 2014). The rich data provided within the lesson documentations allowed us to follow a mixed-method approach by applying quantitative and qualitative analysis of the lesson documentations.

Research questions

Following the current debate within motivational research, we investigated whether technology-related self-efficacy and perceived utility-value beliefs vary (i.e., are state variables) or remain stable across lessons (i.e., are trait variables). Therefore, we investigated the variability and differences of motivation across entries:

Research question 1: Do teachers' intra-individual technology-related self-efficacy (*RQ1a*) and utility-value (*RQ1b*) vary or remain stable across entries in the teacher-diary?

Second, based on general findings of teaching quality (Praetorius et al., 2018), we also investigated potential variability of the quantity (i.e., *RQ2a* frequency of technology integration) and quality of technology integration (i.e., *RQ2b* technology exploitation and teaching quality).

Research question 2: Does the quantity (*RQ2a* frequency) and quality (*RQ2b* technology exploitation, task-specific and task-general teaching quality) of technology integration vary or remain stable across entries in the teacher-diary?

More importantly, we were interested in potential relations between teacher motivation (i.e., self-efficacy and utility-value) and the quantity and quality of their technology integration. Therefore, we examined whether intra-individual technology-related self-efficacy and utility-value beliefs accounted for the quantity (i.e., frequency of technology use *RQ3a*) and quality of technology integration across entries (i.e., *RQ3b* technology exploitation and teaching quality).

Research question 3: Does the individual level of self-efficacy and utility-value predict the quantity (*RQ3a* frequency) and quality (*RQ3b* technology exploitation and task-specific and task-general teaching quality) of technology integration?

To investigate our research questions, we followed a mixed-method approach (McCrudden et al., 2019): We used quantitative analyses to investigate the variability of technology integration and teacher motivation, and to trace potential relations of these key constructs across lessons, by applying recently applied methods such as variance component analysis (see Mantzicopoulos, French, Patrick, Watson, & Ahn, 2018; Praetorius et al., 2018) and linear mixed effect models (Duckworth, Tsukayama, & May, 2010). These quantitative analyses were accompanied by qualitative analyses to investigate potential accounts of the instructional contexts, which may have evoked potential intra-individual variability. We followed a criterion-based sampling approach and selected prototypical cases of the lesson documentations to reconstruct potential contextual determinants (White, DeCuir-Gunby, & Kim, 2019).

7.2 Method

7.2.1 Research context

The current study was conducted within the context of an initiative of the ministry of education of a federal state in Germany (Baden-Württemberg). Within this initiative, 28 classes from seventh grade secondary academic track were equipped with mobile technology (i.e., tablets) and infra-structure (i.e., internet access). During the initiative, the teachers were asked to integrate technologies into their daily classroom practices. However, the teachers were not enrolled in professional development programs; rather, they had to adopt technologies into their teaching without any further support. The study was conducted in the beginning of the initiative. Thus, the research context allowed us to investigate potential trajectories and relationships of teacher motivation and technology integration in the context of beginning technology implementation under real conditions with high ecological validity.

7.2.2 Participating teachers

All the teachers of the initiative were invited to participate in the study via the school coordinators, who were regular teachers at schools but additional local contact persons for the initiative. Sixty-seven teachers originally agreed to participate in the study. However, given that the study was conducted on top of the regular teaching tasks (full-time), a large proportion of teachers only made one or two entries (*n* = 49). The limited amount of entries, therefore, did not allow to investigate the variability of teacher motivation and its impact on technology integration. Therefore, we decided to select only data from teachers who provided at least three entries across the six weeks. This procedure resulted in a sample of *n* = 18 teachers comprising 83 entries (*M* = 4.61 entries per teacher on average, *SD* = .78).

The teachers were teaching in seventh grade academic track in German secondary schools. They were comparably distributed across different subjects (i.e., German, English as a foreign language, Mathematics, and History). The teachers had on average 14 years (*SD* = 7.91) of teaching experience and were 42 years old on average (*SD* = 8.55); nine teachers were female. All teachers were fully certified and had successfully graduated from the study phase of a university teacher education program (approx. 5 years of studies) and the mandatory and structured induction phase (approx. 2 years). At the time of their training, teaching with technologies had not been a mandatory part of German teacher education.

Systematic analysis of included and excluded teachers

As the selection procedure could have resulted in biased data (e.g., inclusion of very motivated teachers), we ran a set of χ^2- and *t*-tests on critical confounding variables to ensure the validity of our findings. Thus, we compared the included teachers of the current study to the remaining teachers of the initiative. Note, that such comparisons with the larger reference group were possible by reanalyzing secondary data of the main initiative (see http://tablet-tuebingen.de/). None of the statistical tests approached statistical significance: The teachers of the current study did not differ from the overall teacher sample[4] regarding their gender, $\chi^2(1)$ = 0.17, *p* = .794; age, *t*(90) = -1.83, *p* = .071, and teaching experience, *t*(90) = -1.61, *p* = .112. Furthermore, the teachers' perceived utility-value, *t*(88) = .49, *p* = .655, and their self-efficacy, *t*(86) = -1.42, *p* = .159 were comparable to the main sample of the tabletBW study (see Chapter 7.1.1 for the descriptive statistics).

7.2.3 Design

We followed an experience sampling approach over a period of six weeks with a newly developed web-based teacher-diary. Teachers were required to make one entry into the teacher-diary per week (i.e., documentation of one lesson, self-efficacy, and utility-value). The dependent variables encompassed the quantity of technology integration (i.e., frequency of technology integration, type of technology integration), as well as the quality of technology integration (i.e., technology exploitation and teaching quality) of the documented lessons per entry. As predictors, we used teachers' technology-related self-efficacy and perceived utility-value per entry.

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[4] *Note*: The degrees of freedom vary because of missing data within the different scales in the main sample.

The teacher diary

The web-based teacher-diary was implemented in questback.de (Questback, 2017). The teacher-diary was piloted with six teachers from the initiative tabletBW to determine the feasibility and technical implementation. Based on feedback of the teachers, we reduced the scales and re-formulated some of the instructions. None of the teachers who took part in the pilot phase participated in the current study.

Motivation section. Based on expectancy-value theory (Eccles & Wigfield, 2002), we assessed teachers' technology-related self-efficacy and their perceived utility-value regarding the use of technology for teaching as critical motivational states of technology integration.

*Technology-related self-efficacy***.** To assess teachers' self-efficacy regarding the use of technology for teaching, we used four adapted items by Rigotti and colleagues (2008; e.g., "In this week, I was able to cope with the demands of technology-enhanced teaching."; "In this week, I was able to use technology to encourage the learning of the students."). The teachers rated the items on a 4-point Likert scale from 1 (*strongly disagree)* to 4 (*strongly agree*). The reliability of the scale was good, Cronbach's α = .843.

*Utility-value***.** We applied two adapted items from van Braak and colleagues (2004; i.e., "In this week, I thought technologies were useful for my lessons."; "In this week, I really appreciated the added value of introducing technology into the classroom.", see also Study 1, Chapter 6; Sang et al., 2010; Teo et al., 2018). Again, the teachers rated their perceived utility on a 4-point Likert scale from 1 (*strongly disagree*) to 4 (*strongly agree*). The reliability of the scale was good, Cronbach's α = .846.

Lesson documentation section. To examine the quantity of technology integration, teachers were asked to indicate how many lessons they taught this week in total and how often they used technologies ("I taught __ lessons this week and used technologies in __ lessons"). To obtain insights into the quality of technology integration, the teachers were asked to document one prototypical technology-based lesson that had been exemplary for the particular week by means of an open question. To guide teachers in the documentation of the lesson, they received a set of prompts (e.g., "What were the central teaching objectives of the lesson?", "Which instructional method did you use?", "How did you use educational technology during teaching?", "Did the educational technology assist you to achieve your teaching objectives, and if so, how?" see Study 1, Chapter 6; Kramarski, & Michalsky, 2010, for related approaches).

The lesson documentations encompassed on average 110 words (*SD* = 81) and were used to a) code the type of technology usage as a further proxy for the quantity of technology integration, and b) rate the quality of technology integration. Additionally, teachers were asked to rate the smoothness (Kounin, 1970) of their technology integration within the described lesson on a 5-point Likert scale from 1 (*does not apply*) to 5 (*does apply*), as a proxy for the task-general teaching quality while using technology (i.e., "In this week, the technology integration worked smoothly.").

7.2.4 Analysis and coding

Quantity of technology integration

Frequency of technology integration. Based on the information of lessons taught in total and lessons taught with technologies, we calculated the proportion of technology integration for each week.

Type of technology integration. We analyzed the different applications of educational technologies that teachers described in their lesson documentations and summarized them using an inductive categorization process (Mayring, 2015). This resulted in nine dominant types of educational technologies. The interrater agreement between the two raters for 39% of the lesson plans was good with 87% of the total agreement (Kappa = .57). Please note that Cohen's κ is less accurate when there are large variations between the overall occurrences of categories and therefore a difference between Cohen's κ and the exact agreement occurred (Wirtz & Caspar, 2002).

Quality of technology integration.

Technology exploitation. To assess whether teachers were able to exploit the distinct functions of technologies, we analyzed the quality of technology exploitation within the documented lessons. We provided four subcategories to specify the judgements, see Table 9. These categories encompassed the level of innovativeness of technology adoption within the lesson based on the hierarchical framework by Hughes et al., (2006), as well as the level of exploitation of distinct affordances of technology integration based on research on technology-enhanced learning. For each category, the teachers could receive 0 (i.e., subcategory not applied) to 3 points (i.e., subcategory ubiquitously applied), yielding a possible maximum score of 12. Two trained raters coded 20% of the lesson documentations. Interrater reliability was very good, *ICC* (2,1) = .81 (Koo & Li, 2016; Wirtz & Caspar, 2002). Thus, only one rater coded the remaining lesson documentations.

Table 9

Coding Scheme for Quality of Technology Integration

Subcategories	Description	Examples (excerpts of lesson documentations)
Task-specific teaching quality		
Provision of cognitively challenging activities	Teacher provided students with tasks which they have to think about thoughtfully.	Students had to search on a screenshot of the map of our city (provided in Geogebra) for the point with exactly the same distances from the houses of three students to explore the circumference of a triangle as the intersection of the two perpendicular bisectors. *(mathematics lesson)*
Support of students' knowledge construction	Teacher supported students' discovery of overall context of the lesson topics.	The students independently explored the differences between Protestant, Calvinist and Catholic dogma and summarized the results in a digital mind map. *(history lesson)*
Encouragement of students' participation	Teacher encouraged students to explain connections of different concepts, ideas and conceptions.	Students watch an explanation video on *relative clauses* and had to write down the rules on their own and we discussed this. *(EFL lesson)*
Provision of instructional guidance	Teacher provided instructional guidance to enhance students' learning processes.	Students added information to a pre-structured timeline and received additional information via airdrop if they did not know how to continue. *(history lesson)*
Technology exploitation		
Innovativeness of technology adoption	The technologies are used to make the course of the lesson more effective and enable a new way of teaching.	Students worked on an interactive working sheet with hyperlinks to explanation videos and virtual simulations which they could look at if they had troubles. *(mathematics lesson)*
Application of adaptivity	The technologies are used to adapt the content on students' knowledge (e.g., based on technology-based formative assessment).	Students used learningapps.org to practice and received automatically feedback and additional information if they did a mistake. *(EFL lesson)*
Application of multimodality	The technologies are used to present multiple forms of representation (e.g., video, audio, pictures).	Students had to invent a story to a given graph and had to record an audio or video message about the story. *(mathematics lesson)*
Application of interactivity	The technologies are used to heighten students' communication and collaboration.	Students worked simultaneously on an overview of the topic in one live-synchronized document and discussed the information provided by others with the chat application. *(Latin lesson)*

Teaching quality. The teaching quality was assessed with respect to task-specific and task-general strategies. The *task-specific teaching quality* of the documented lessons was rated on the dimensions of cognitive activation and individual learning support. The raters had four subcategories available to specify their judgments, see Table 9 (adapted Study1, Chapter 6; Hugener et al., 2009; Kunter et al., 2013; Praetorius et al., 2018). For each subcategory, the teachers could receive 0 (i.e., subcategory not applied) to 3 points (i.e., subcategory ubiquitously applied), yielding a possible maximum score of 12. To determine the reliability of our categorization, again, two trained raters coded 20% of the lesson documentations. Interrater agreement was very good, *ICC* (2,1) = .92. Thus, only one rater coded the remaining lesson documentations. Additionally, as a proxy for the task-general teaching quality (i.e., classroom management), we used teachers' self-ratings of the smoothness item, as documentations likely are less capable to measure teachers' classroom practices and research showed that teachers' are capable to assess their classroom management (Aldrup, Klusmann, Lüdtke, Göllner, & Trautwein, 2018; Wagner et al., 2016).

Quantitative analysis

Variability of the measures. To investigate whether teacher motivation varied, we followed suggestions by Praetorius et al. (2018) and applied variance component analysis with the help of generalizability theory (cf. G theory). Variance component analysis allows the separation of different factors (i.e., variance components) which determine a distinct measure. Therefore, variance explained by intra-individual or inter-individual differences, and residual variance can be identified (Praetorius, Lenske, & Helmke, 2012; Praetorius, Vieluf, Saß, Bernholt, & Klieme, 2016). By applying variance component analysis based on G theory within the framework of multilevel analysis, the analysis accounts for the nested structure of longitudinal data (i.e., measuring points / entries nested within teachers). Therefore, in the current study, variance components can be separated which are due to differences between the teachers (i.e., variance explained by the teacher), differences across lessons (i.e., variance explained by the different lessons of one teacher), and unexplained variance. When distinct analyses show high proportions of residual variance, they indicate that a large proportion likely emerges due to other prevailing contextual differences which are not captured in the mathematical model. We applied the *gtheory* package (Moore, 2016) implemented in the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015) within R Studio (R Core Team, 2019).

Relation of motivation and technology integration. To investigate the relations of self-efficacy and utility-value and the quantity and quality of technology integration we applied growth-curve models. Growth curve models are a special case of linear mixed effects models to account for the nested data structure, as measurement points were nested within persons (Duckworth et al., 2010). Growth curve models enable to analyse “inter-individual variability in intra-individual patterns of change over time” (Curran, Obeidat, & Losardo, p. 2). Within these models, each teacher served as her or his individual baseline measure (i.e., intercept) and the change (i.e., slope) from one measuring point to the subsequent measuring point was analyzed. The models considered the entries (i.e., different measurement points over time) to be nested within teachers, so ‘entries’ represented Level 1 and ‘teachers’ represented Level 2. The dependent variables comprised the measures for quantity and quality of technology integration (i.e., frequency, technology exploitation, task-specific and task-general teaching quality). Entries (as dummy-coded variable representing the different measuring points over time), self-efficacy and utility-value were included as predictors. For each dependent variable, the (unstandardized) estimates, standard error and 95% confidence interval (*CI*) are reported. If the 95% *CI* did not encompass zero, the distinct predictor can be interpreted as being significant. We applied the *lmer* command of the *lme4* package (Bates et al., 2015) of R Studio (R Core Team, 2019).

Qualitative analysis

The main aim of the qualitative analysis was to understand which contextual factors accounted for the potential variability of teacher motivation and their technology integration across entries. Therefore, the analysis unit of the qualitative investigations was the open-ended lesson documentation section. We followed a criterion-based sampling approach, and purposefully selected representative cases of teachers (regarding variability, motivation, and technology integration; see White et al., 2019 for related approaches). Additionally, we took care of equally representing teachers’ demographics. We followed the approach of qualitative content analysis (Cho & Lee, 2014; Mayring, 2015): First, we segmented the lesson documentations of each teacher in instructional units and generalized each unit to a more abstract level with special focus on the particular technology integration, content taught, pedagogical approach and important contextual factors. Second, commonalities and differences between the different units across lessons of one teacher were identified and generalized on an abstract level. Based on this abstraction, we identified two lessons of each teacher with the largest discrepancies in their technology integration. Finally, commonalities and differences between the selected lessons across teachers were identified and conclusions were derived. To refine our analysis and ensure the rigor of our qualitative analysis, each step and especially the conclusions were discussed among the authors.

7.2.5 Procedure

We informed the teachers that the scope of the study was to learn more about their technology integration and potential boundary conditions during teaching with technology. All the teachers provided written consent to participate in the study. We obtained ethical approval from the Ministry of Education, Culture, Youth and Sports of regional state (Baden-Württemberg). The link to the teacher-diary was sent via email. At the first log-in, the teachers provided information on their demographic data (i.e., age, gender). Afterwards, they were asked to provide one entry with one lesson documentation per week over a period of six weeks. One entry lasted approximately 15 minutes. At the end of the study, the teachers received a computer-based report about the central trajectories of their motivation, their technology application, and the self-assessed quality of technology-enhanced lessons as compensation.

7.3 Quantitative Findings

7.3.1 Preliminary explorative analyses

For the descriptives of the measured constructs across all measurement points and for bi-variate cross-sectional correlations between the general means of the different constructs across lessons see Table 10 and Table 11.

The analysis of the types of technology usage indicated that teachers most frequently used generic technologies, such as presentation tools (e.g., keynote, PowerPoint), e-text readers (e.g., e-books, pdf-documents), exercise software or file transfer services (e.g., airdrop, cloud services), see Figure 12. However, teachers rarely used subject-specific tools, such as virtual simulations (e.g., GeoGebra), or formative assessment technologies, such as audience response systems (e.g., kahoot, socrative).

Table 10

Means and Standard Deviations of the Variables Across Lessons

	M	*SD*
Motivation[a]		
Self-efficacy	3.25	.703
Utility value	2.94	.881
Quantity of technology integration		
Frequency of technology use[b]	76.97	32.851
Quality of lessons		
Technology exploitation[c]	1.92	.678
Task-general teaching quality[d]	4.10	.993
Task-specific teaching quality[c]	2.15	.443

[a] Teacher ratings ranged from 1 (*strongly disagree*) to 4 (*strongly agree*), [b] Values represent percentage scores, [c] Values represent means of the rating 0 (*subcategory not applied*) to 3 (*subcategory ubiquitous applied*), [d] Values represent means of the rating from 1 (*does not apply*) to 5 (*does apply*).

Table 11

Bivariate Correlations of the Mean of the Investigated Variables across all Entries

	1	2	3	4	5
1 Self-efficacy beliefs					
2 Utility value	.677**				
3 Frequency of technology integration	.190	.282**			
4 Technology exploitation	.203	.400**	.173		
5 Task-general teaching quality	.486**	.520**	.195	.031	
6 Task-specific teaching quality	.181	.275*	.104	.848**	.037

Note. * $p < .05$. ** $p < .001$.

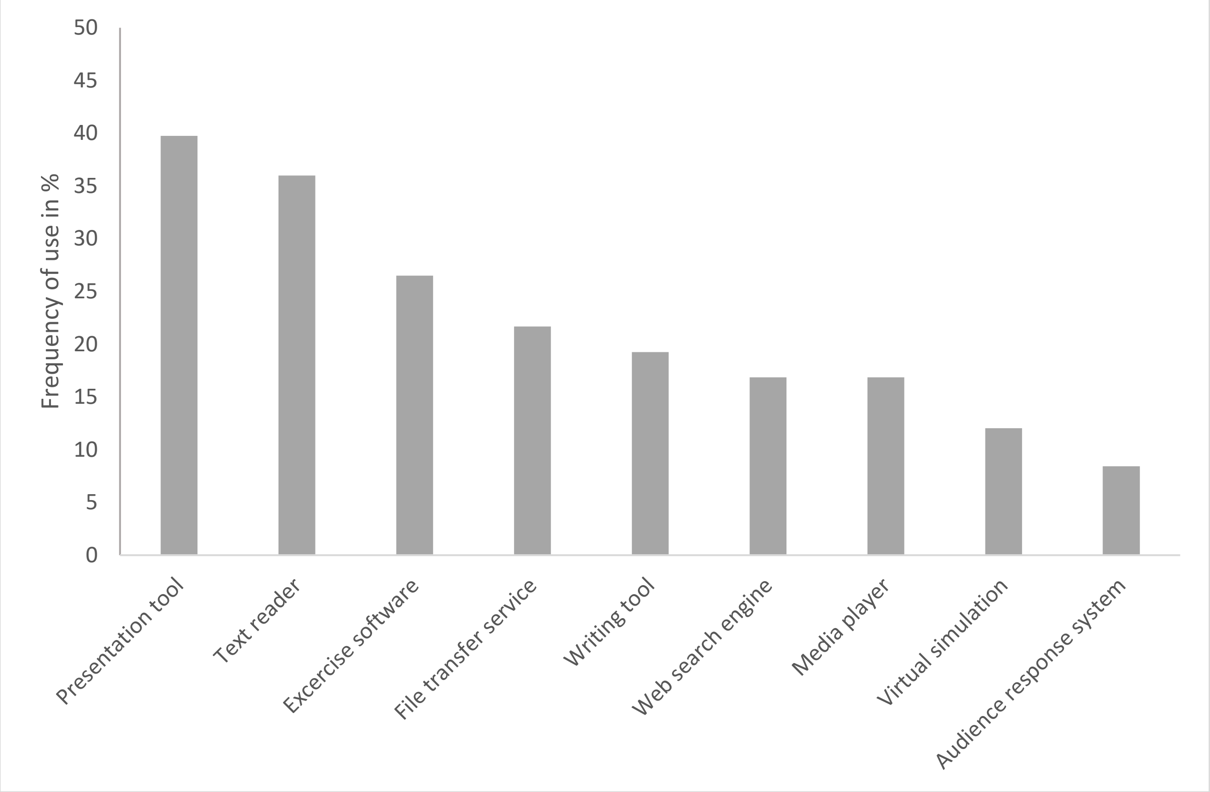

Figure 12. Type of used Technologies within the documented Lessons. Bar Charts represent the Frequency of Use per Teacher.

7.3.2 *RQ 1*: Intra-individual variability of motivation

To investigate the intra-individual variability of self-efficacy (RQ1a) and utility-value (RQ1b) across entries, we used variance component analysis to identify the variance explained by systematic differences between teachers, across lessons and unexplained variance, see

Figure *13*. We found that a considerable amount of variance of teachers' self-efficacy and utility-value could be explained by stable teacher traits (*VC* > 27 %). The amount of variance explained by systematic differences during the course of lessons was relatively low (*VC* < 6%). Most of the variability of teacher motivation was unexplained variance. These findings suggest that besides distinct motivational traits, a large proportion of variance likely emerged due to differences in instructional contexts.

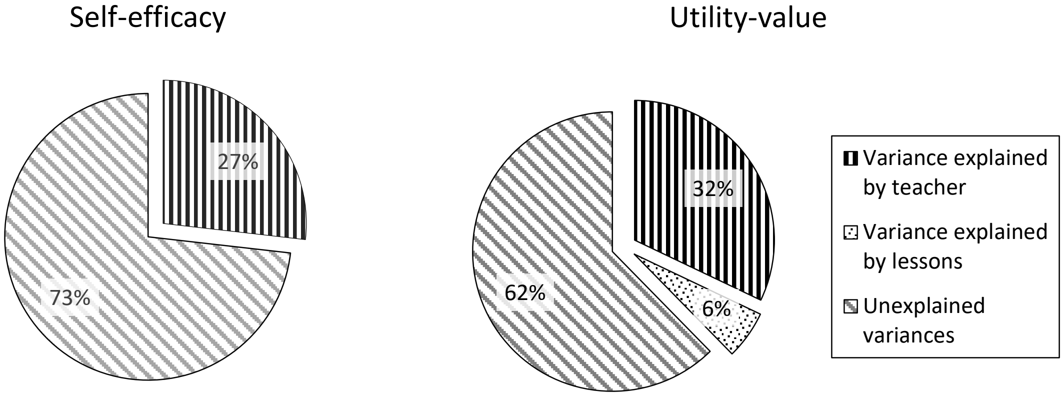

*Figure 13.*Variance Component Analysis for Teachers’ Self-Efficacy (left) and Utility Value (right).

7.3.3 *RQ 2*: Variability of quantity and quality of technology integration.

To investigate the variability of the quantity (RQ2a) and quality of technology integration (RQ2b), we again applied variance component analysis (see Figure 14). We found low amounts of explained variance by teacher traits for the frequency of technology integration and the task-specific indicators of teaching quality (i.e., cognitive activation and individual learning support, *VC* < 11 %). For the smoothness of the lessons, as a task-general indicator of teaching quality, the amount of variance explained by the teachers (*VC* = 25 %) was considerably larger, suggesting that a significant proportion of the task-general teaching quality could be explained by relatively stable teacher traits. Again, only a small amount of variance could be explained by systematic differences between the lessons (ranging from 1-5%), and the highest variance component remained unexplained variance (70-88%). Overall, the high residual variance across our measures of the quantity and quality of technology integration demonstrated that most of the variability was not explained by systematic teacher traits or general time course, but highly depended on contextual factors emerging from the particular teaching environment.

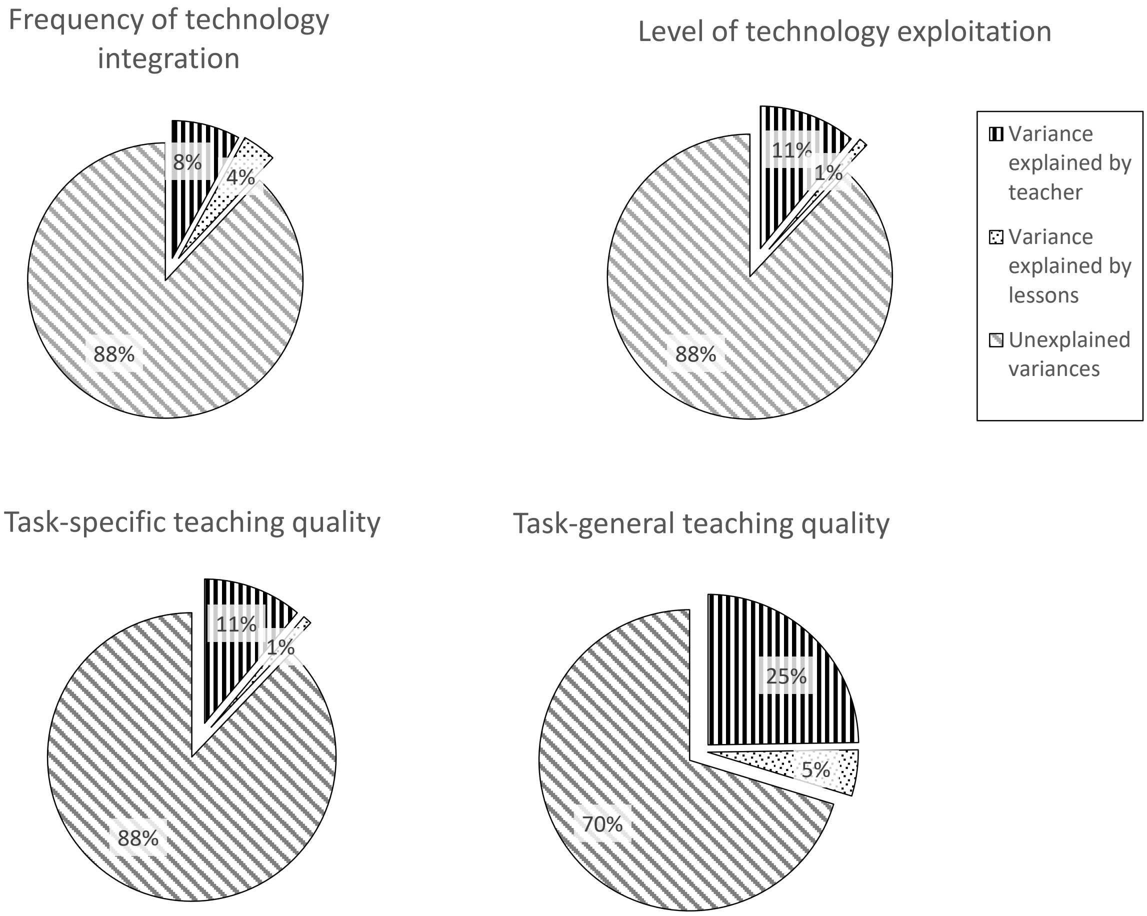

Figure 14. Variance Component Analysis for the Frequency of Technology Integration (upper left), Level of Technology Exploitation (upper right), Task-specific Teaching Quality (lower left), and Task-general Teaching Quality (lower right).

7.3.4 *RQ 3*: Motivation and technology integration.

We analyzed systematic links of motivational states (i.e., self-efficacy, utility-value) and the technology integration by applying linear mixed effect models. The analysis indicated that self-efficacy was not related to the frequency of technology integration (RQ3a), *Estimate* = -.880, *SE* = 4.914, 95% *CI* [-10.510, 8.752], as zero was not included in the confidence interval, however, utility-value was, *Estimate* = 7.910, *SE* = 3.896, 95% *CI* [0.273, 15.547]. This finding indicates that the quantity of technology integration was related to the perceived utility-value of technology.

A similar pattern emerged for the quality of technology integration (RQ3b): Self-efficacy was neither related to technology exploitation, *Estimate* = -0.112, *SE* = 0.131, 95% *CI*

[-0.370, 0.145], nor to task-specific teaching quality, *Estimate* = -0.027, *SE* = 0.088, 95% *CI* [-0.201, 0.146]. However, again, utility-value was related to technology-exploitation, *Estimate* = 0.367, *SE* = 0.325, 95% *CI* [0.161, 0.573], and task-specific teaching quality, *Estimate* = 0.189, *SE* = 0.070, 95% *CI* [0.050, 0.327]. Interestingly, both utility-value and self-efficacy predicted the task-general teaching quality (i.e., smoothness of technology integration): self-efficacy, *Estimate* = 0.448, *SE* = 0.165, 95% *CI* [0.124, 0.771]; utility-value, *Estimate* = 0.417, *SE* = 0.128, 95% *CI* [0.166, 0.669]. This finding indicates that besides the perceived utility, self-efficacy was strongly linked to maintaining high levels of classroom management in technology-based teaching environments.

Overall, the quantitative findings suggest that teacher motivation and teaching quality can be regarded as variable states which are likely constrained by individual characteristics emerging from differences of the particular instructional context. Additionally, the individual level of perceived utility was significantly linked to the quantity and quality of technology integration.

7.4 Qualitative Analysis

The primary goal of the qualitative analysis was to understand potential characteristics and constituents of the variability of utility-value and its relationship to the quality of technology integration. Therefore, we identified prototypical teachers: Klaus (44 years old, history teacher), Patrick (30 years old, mathematics teacher), and Anna (48 years old, English as Foreign Language teacher), see Figure 15 and Figure 16 for their trajectories of motivation and technology integration.

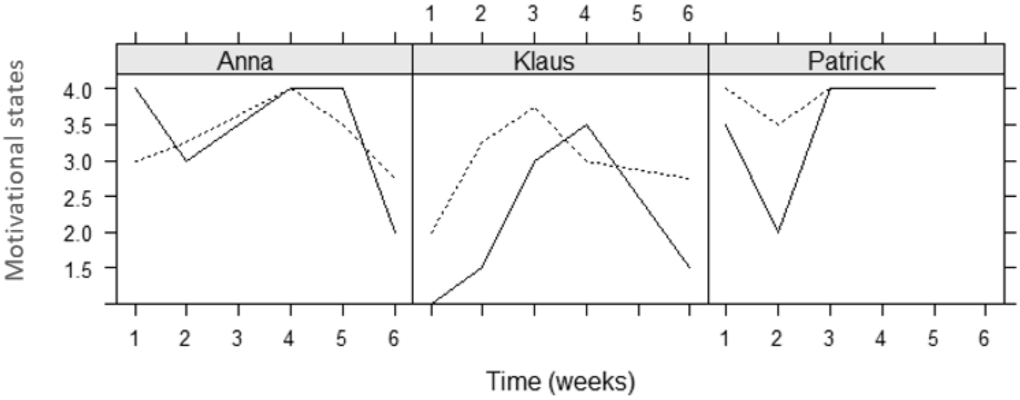

Figure 15. Plots of individual Trajectories of perceived Utility Value (solid line) and Self-Efficacy (dotted line) of the Exemplary Teachers of the Qualitative Analysis.

Note. Utility value and self-efficacy was rated on a 4-point Likert scale per week (x-axis) across six weeks (y-axis).

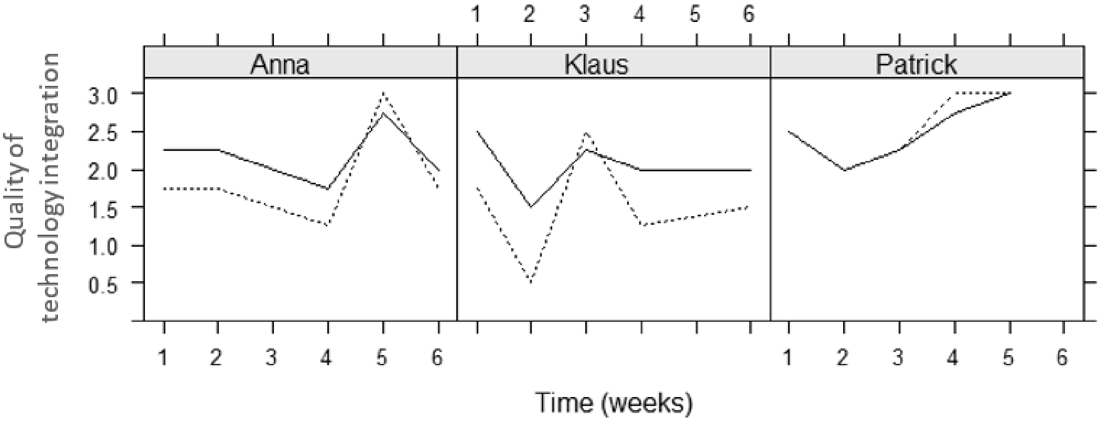

Figure 16. Plots of individual Trajectories of the Quality of Technology Integration (i.e., task-specific Teaching Quality (solid line) and Technology Exploitation (dotted line) of the Exemplary Teachers of the Qualitative Analysis.

Note. Task-specific teaching quality and technology exploitation was rated on a 0 to 3 scale each week across six weeks (y-axis).

7.4.1 Klaus: An example in history teaching.

Klaus was a history teacher with 13 years of working experience who judged himself as novice in technology integration. He showed reasonable variability of utility-value and variability of technology integration over time. In his first documented lesson, he showed low levels of utility-value. In this lesson, he planned a learning activity which aimed at fostering students' critical thinking about the potential consequences of the early European exploration in the 15th century. To achieve these goals, he implemented a Padlet (a live-synchronized whiteboard application to initiate collaborative learning activities) but had to stop the learning activity:

> The formation of judgement should be supported by joint exchange using a Padlet. Two problems led me to break this off after a few minutes: 1) Apart from a few exceptions, the posts were extremely superficial, so that no process of judgement formation was recognizable. 2) (…) This was abused by a student to an offensive post about a not present classmate. (Klaus, entry week 1)

This documentation may be indicative that the given instruction during the collaborative learning activity was not clear enough, which resulted in the superficial judgments. Furthermore, the low levels of classroom management resulted in an offensive post by a student. Klaus proceeded as follows:

> Second, we prepared a panel discussion. One student suggested to film the subsequent panel discussion. I spontaneously agreed on that, however, the filming did disturb the students' discussion. Therefore, I stopped the filming and the students proceeded with the discussion. (Klaus, entry week 1)

The spontaneous addition of recording resulted in additional disturbances during the discussion, which likely decreased the general teaching quality of the lesson. Together, week one illustrates that Klaus' lack of preparation regarding technology integration and the resulting students' disturbances likely determined the low levels of perceived utility-value and quality of technology integration. Therefore, Klaus' utility-value and quality of technology integration likely mutually dependent.

In the fourth week, Klaus perceived high utility-value. In his lesson, he dealt with the German Peasants War. He used the mBook (https://mbook.schule/digitale-schulbuecher/) which is a digital textbook that comprised digital learning activities, based on multiple-source comprehension: "First, I showed a picture, then students worked out the connections of the Memminger declaration and Reformation with the help of different texts in the mBook, and worked on tasks provided within the book." (Klaus, entry week 4) Relying on existing digital materials allowed Klaus to assure a smooth course of the lesson and to realize relatively high levels of teaching quality.

7.4.2 Patrick: An example in mathematics teaching.

A similar pattern emerged in the case of Patrick, a mathematics teacher with four years of teaching experience, but who described himself as a pragmatist who likes to integrate technologies. In the second week, he had low utility-value regarding technology integration. In the described lesson, he aimed at using a collaborative whiteboard app to collect and categorize linear equations and their transformations. Similar to Klaus, the learning activity did not work, as it resulted in large disturbances among students, which led him to conclude: “It was totally chaotic, as also students deleted correct solutions.” (Patrick, entry week 2)

Similar to Klaus’ lesson, the instruction of the learning activity was likely not clear enough, and students would have needed more guidance while using the technology in the collaborative learning activities. Contrarily, in week 5, he used online learning material comprising simulations, video explanations, and adaptive exercises with online feedback from the GeoGebra Materials Platform, an international repository enabling teachers to use comprehensive interactive learning and teaching resources, which resulted in a lesson of high teaching quality: “The students discovered the proof of the theorem with the help of a GeoGebra book [dynamic geometry software]- perfect simulation and visualization of the processes of the theorem – and documented it on a worksheet.” (Patrick, entry week 5)

This finding reflects the fact that high quality of technology integration requires teachers to thoroughly prepare their instruction. Additionally, the examples highlight that the use of content-specific material for their lessons may assist teachers to more thoroughly integrate technology and heighten teaching quality.

7.4.3 Anna: An example in English teaching.

Anna was an experienced English teacher with 21 years of teaching experience, describing herself as a pragmatist who likes to integrate technologies into her teaching. During the course of her teaching, the main theme was the textual analysis and interpretation of a specific narrative reading. In her first week, she reported high utility-value, which was also reflected in her lesson documentation: “Students explored the places where the protagonists live [with GoogleMaps Streetview], created screenshots, copied them into an Adobe Pages document and described the district in which the main characters live.” (Anna, entry week 5)

Contrarily, in the following week, she perceived low utility-value. “Using the PDF Viewer, the students created a graph to describe the evolution of the relationship between two characters of the book.” (Anna, entry week 6). In this lesson, Anna likely did not fully exploit the potential of educational technology, as she simply substituted analogous learning activities (i.e., drawing) by tablet-based activities. This finding suggest that besides general aspects of instructional quality, also the fit between topic and educational technology affected the perceived utility and the quality of technology integration.

The qualitative analysis show that it was easier for the example teachers to implement high teaching quality with technologies, if they used existing domain-specific applications. These applications already appropriately integrated the relevant pedagogy, content and affordances of the technology. Therefore, in these cases, the teachers were not faced with the challenge of integrating generic applications in a meaningful way into their domain-specific lesson procedure. More importantly, our qualitative analysis suggested that teachers’ motivation and technology-enhanced teaching quality may be reciprocally dependent on each other. Therefore, it can be concluded that teacher motivation should not only be regarded as a source but also as the result of teachers’ actions in the classroom.

7.5 Discussion

In the current study, we investigated the trajectories and relations of in-service teachers’ motivation and technology integration by applying an experience sampling approach within daily classroom practice. Our findings showed that both motivation and technology integration were highly variable among documented lessons and therefore varied from situation to situation. Additionally, we found that part of the variability of the quality of technology integration was linked to individual differences of teachers’ perceived utility-value of technology integration. Our qualitative analyses highlighted the reciprocal relationship between utility-value and technology integration, and their dependency on the instructional context in which technology was adopted. These different instructional contexts may have been responsible for the differences in motivation and technology integration.

7.5.1 Motivation and technology integration are context-sensitive

As a first contribution, we found that teachers’ technology-related motivation varied across the lessons. Even though, approximately 30% of the motivation could be explained by stable traits, 60 - 70% were determined by specific instructional contexts of the different lessons. Therefore, our findings contribute to general motivation research, which has emphasized the situated character of human motivation (Reeve, 2016), and extends the findings to professional domains such as teaching. In previous studies, self-efficacy remained rather stable across lessons, which could be due to the longer time period investigated (Holzberger et al., 2013; Praetorius et al., 2017). Therefore, the measures applied in those studies were more related to general teaching self-efficacy and not as context-sensitive as our measures which directly asked about the self-efficacy in the lessons during the specific documented week. However, these contradicting results should be further investigated in future studies.

Additionally, we found high variability in the quality of technology integration across lessons. In line with general research on teaching quality (Fauth et al., 2019; Praetorius et al., 2014) the study demonstrated that teaching quality is not a stable characteristic of teaching, but rather depends on individual contexts. The qualitative analyses further illustrated potential contextual variables that depend both on the teacher and their students, but also on the subject-matter and material used. When teachers relied on pre-given material which already implemented the specific potential of technologies in a meaningful way, they were more able to establish high teaching quality. This finding can be interpreted twofold: 1) teachers need more domain specific technology-enriched material, or 2) teachers need specific training to implement domain-general technologies into their distinct instructional context.

In sum, our findings highlight the need to investigate the circumstances and contexts which accounted for differences in teaching quality (Turner & Meyer, 2000).

7.5.2 Quality of technology-enhanced teaching is related to utility-value

The findings extend previous research on relations between teacher motivation and technology integration (e.g., Scherer et al., 2019), as despite the large variability in the key variables, perceived utility was significantly related to the quality of technology integration across lessons and contexts (see also Study 1, Chapter 6).

Self-efficacy did not account for the quality of technology integration and task-specific teaching quality, but only for the task-general teaching quality. However, based on expectancy-value theory, higher levels of self-efficacy should be important for the successful accomplishment of a task, such as the successful technology integration and therefore task-specific teaching quality. Also Author (20xxa) did not find significant relations between self-efficacy and the quality of technology integration and proposed that self-efficacy may rather be important for the implementation of distinct technology, mostly indicated by the quantity of technology integration (see also Farjon et al., 2019; Petko, 2012). For the quality of technology integration, utility-value might be more important, as perceived utility likely allows teachers to think about distinct potentials of technologies, which could result in higher exploitations of the technology. However, in the present study there was only a relationship between self-efficacy and task-general teaching quality and neither a relation of self-efficacy and frequency of technology integration nor quality of technology integration. Therefore, the direction and nature of the relationship is still an open question and should be addressed in further studies.

As a first hint, the qualitative analysis suggest that the relation of teacher motivation and technology integration is more of a reciprocal nature: If the perceived high utility, they integrated the technologies in a high qualitative manner (e.g, used technologies to heighten students' cognitive activation). Additionally, vice versa, if the teachers had positive experiences with technologies in the classroom, they perceived higher utility of educational technologies. Prospectively, the question should therefore be addressed whether this reciprocal mechanism holds true for larger teacher samples. It could also well be that a certain amount of general attitude towards the utility (as a trait component) is a necessary pre-condition for technology integration and a contextualized utility (as a state component) may depend on situational and concrete experiences during teaching with the technologies.

7.5.3 Limitations and future research

One central caveat refers to the fact that we realized a correlational design, which does not allow for investigating the causal effects of utility-value on technology integration (or vice versa). Therefore, based on our study, it is unclear whether utility-value would be a concurrent facet of *successful* technology integration, a causal factor determining the quality of technology integration, or whether utility-value is a consequence of high quality of technology integration. As a further development of our study, we would see to experimentally manipulate teachers' utility-value by inducing different levels of utility-value (see Brisson et al., 2017; Canning et al., 2018) to investigate whether utility-value would have a causal role in determining technology integration. Additionally, we must admit, that we relied on teachers' documentations, and had no direct observations of technology integration, which may have affected our findings. Therefore, we see the need of replicating our findings in more contextualized settings, in which actual teaching behavior across multiple measurement points is analyzed, for instance by means of video-analyses.

7.5.4 Conclusion

To conclude, the present study helps to get a better understanding of teachers' motivational states which enable them to integrate technology across situations. Our findings indicate that their motivation and particularly current perceived utility-value of educational technologies play a critical role in integrating technology in a qualitatively high manner that largely depends on the particular context. From a teacher education perspective, teachers have to be aware of the influence of contextual aspects such as their motivation, as well as the quality and quantity of their technology integration.

8 *Study 3*: BRINGING TOGETHER TWO WORLDS

Technology Integration: A Synergism between Expectancy-Value Theory and Technology Acceptance Models

The content of the following chapter is currently under review in Computers & Education. The proportional contributions of the different co-authors to the manuscript are presented in the subsequent table. This article may not exactly replicate the final version published in the journal. It is not the copy of record.

Author	Author position	Scientific ideas %	Data generation %	Analysis & interpretation %	Paper writing %
Iris Backfisch	first author	60 %	0 %	75 %	65 %
Ronny Scherer	second author	15 %	10 %	25 %	10 %
Fazilat Siddiq	third author	15 %	90 %	0 %	10 %
Andreas Lachner	fourth author	5 %	0 %	0 %	10 %
Katharina Scheiter	fifth author	5 %	0 %	0 %	5 %

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Abstract

Integrating technologies in education has received much attention, often followed by arguments such as its great potential to enhance teaching quality and students' digital literacy. However, research demonstrated that teachers rarely use technologies likely because of low levels of technology-related motivation. Theories on teacher motivation, however, differ in how they conceive the influence of motivation on technology integration. Based on the Expectancy-Value Theory a *concurrent mechanism* can be assumed according to which self-efficacy and utility value of educational technologies directly affect technology integration. Alternatively, based on Technology Acceptance models a *cascade mechanism* is assumed, which describes an indirect relation of self-efficacy and technology integration that is mediated through teachers' value beliefs. To further investigate and disentangle these conflicting assumptions, we conducted a survey study within a one-to-one technology-enhanced learning context with $N = 524$ in-service teachers. Structural equation modeling showed that concurrent and cascade mechanisms of self-efficacy and utility value were both present in the data. Therefore, the findings indicate that rather than being mutually exclusive, the two perspectives should be integrated. Such an integrated perspective on teacher motivation in the context of technology integration appears more reasonable to inform research and practitioners about the relationships between teacher motivation and technology integration.

8.1 Introduction

Teaching with technologies is advocated within the political as well as the scientific debate (Fraillon et al., 2019; OECD, 2015). In these discussions the potential of technologies to promote distinct teaching and learning processes as well as the necessity of technology integration in schools to develop students' 21st century skills are stressed. Besides the availability of infrastructure (Drossel et al., 2017), research showed that teachers' motivational beliefs are boundary conditions of their technology integration. These motivational beliefs encompass aspects such as teaching enthusiasm, and goal orientation; but also, self-efficacy and perceived utility of technology which are mainly regarded as crucial motivational sources determining technology integration (see Chapter 7, p. 93 and e.g., Scherer et al., 2019; Taimalu & Luik, 2019).

However, the exact nature regarding the relationships and mechanisms among teachers' motivational beliefs (i.e., self-efficacy, perceived utility) and technology integration are yet unclear. For instance, classical motivational belief models (e.g., expectancy-value theory, EVT, Eccles & Wigfield, 2002) assume a concurrent mechanism with direct effects of self-efficacy *and* utility value on technology integration (Taimalu & Luik, 2019). Alternatively, educational technology models (e.g., technology acceptance model, TAM, Scherer et al., 2019) propose a cascade mechanism (i.e., the variables follow a sequential cascade of effects): First, teachers' self-efficacy, as an external variable, is assumed to be related to their perceived utility of educational technology. Second, teachers' utility is assumed to be related to their technology integration. Therefore, according to this cascade mechanism self-efficacy is only indirectly related to technology integration via the perceived utility value of technology integration. To disentangle these two alternative assumptions (concurrent versus cascade mechanism of teacher motivation), we tested them empirically using survey data of in-service teachers (N = 524). All teachers were teaching in a municipality (Asker) where classrooms were fully equipped with technical infrastructure. We performed structural equation modeling to investigate concurrent and cascade associations of teachers' self-efficacy and their utility value on their technology integration. As technology integration in the classroom aims at facilitating students' learning processes as well as heightening their digital literacy, we used measures both for the frequency of in-class technology use during teaching and teachers' emphasis on developing students' digital literacy as potential proxies for technology integration (Siddiq, Scherer, & Tondeur, 2016). This procedure enabled broad and deep insights in the nature of relationships between teacher motivation and technology integration.

8.1.1 Technology integration

The use of technologies in school pursues two main objectives: a) facilitating teaching and learning processes with digital media, and b) supporting students' domain-general digital literacy to participate in a digitalized society (OECD, 2015). Research has demonstrated distinct potentials of educational technology for scaffolding teaching processes, such as learning from multimedia (Moreno & Mayer, 2007; Renkl & Scheiter, 2017) and on-time adaptive learning support (Aleven & Koedinger, 2002; Lachner, Burkhardt, & Nückles, 2016; Ma et al., 2014; Zhu & Urhahne, 2018). Besides supporting learning and teaching processes, technology integration should scaffold students' development of 21st century skills (i.e., digital literacy), as they interact with and critically reflect potential consequences of technologies (Fraillon et al., 2014).

Teachers, however, need appropriate infrastructure to be able to teach with technologies and promote students' digital literacy. Therefore, there is an increasing number of governmental initiatives across countries which provide schools with one-to-one equipment. Within these one-to-one-initiatives typically teachers and students are provided with their own digital devices (Fleischer, 2012). These initiatives are sought to be effective in supporting technology integration and therefore should work as a catalyst for change of daily school practice (Beauchamp et al., 2015; Keane & Keane, 2019; Liu & Milrad, 2010). The International Computer and Information Literacy Study (ICILS) 2013 examined in-class technology use in schools with the usual technical infrastructure in the different countries. Analysis of this data suggest that appropriate technological equipment of schools *alone* is not sufficient for technology integration as the frequency of technology integration was not necessarily related to the level of technical infrastructure in schools of the respective country (Drossel et al., 2017). Therefore, other factors than the mere availability of technologies might be prerequisite for technology integration, such as teachers' professional knowledge and motivation (Mishra & Koehler, 2006; Scherer & Teo, 2019; Scherer et al., 2017).

8.1.2 Teacher motivation

One of the main boundary conditions for technology integration is teachers' motivation (Study 1, Chapter 6; Barton & Dexter, 2019; Scherer et al., 2019). There are two main components of motivational beliefs which have been shown to determine teachers' behavior in their classroom including their level of technology integration: Self-efficacy beliefs of being able to teach with technologies and utility value of teaching with technologies.

Self-efficacy

Self-efficacy are based on one's self-assessments of competencies and confidence in one's own abilities to cope with a certain prospective task (e.g., technology integration, Bandura, 2010; Barton & Dexter, 2019; Marsh et al., 2019; Tschannen-Moran & Hoy, 2007). When it comes to complex tasks, such as technology integration, self-efficacy needs to be conceptualized as a multidimensional construct (see Scherer et al., 2019), as different subskills are required to successfully integrate technology during teaching. The TPACK framework by Mishra and Koehler (2006) conceptualizes these subskills of teachers' professional knowledge regarding technology integration. In the TPACK framework, it is postulated that to successfully adopt technologies, teachers need to have technological knowledge (TK), and integrate this technological knowledge with their professional knowledge of teaching (content knowledge [CK], pedagogical knowledge [PK], and pedagogical content knowledge [PCK]) to successfully integrate technologies during teaching. This knowledge integration then ideally leads to the following embedded knowledge components: technological pedagogical knowledge (*TPK* as knowledge about how to integrate technologies to implement different pedagogical methods); technological content knowledge (*TCK* as knowledge about how to deliver distinct content with technologies); and technological pedagogical content knowledge (TPACK as knowledge on how to teach certain content with technologies in a pedagogical sound way). Overall, the TPACK framework conceptualizes specific dimensions encompassing distinct skills teachers need for the different actions in a technology-enriched classroom. Author (20xxf) investigated the factorial structure and measurement invariance of TPACK captured with a self-assessment questionnaire in a sample of $N = 665$ pre-service teachers. The authors found that the specific TK dimension stands out among all the different specific dimensions of the TPACK framework, as the TK dimension was less related to the other T-dimensions (i.e., TPK, TCK, TPCK). Contrarily the TPK, TCK and TPCK were highly related. Furthermore, the authors emphasized that besides these specific dimensions, there is an underlying, general TPACK factor, on how to use technologies in the classroom which potentially influences all specific T-dimensions. This general TPACK factor should be considered when depicting the different specific dimensions of teachers' knowledge and associated self-efficacy for technology-enhanced teaching (Scherer et al., 2017). Previous research mainly relied on teachers' self-assessments of these knowledge dimensions and confidence in doing different tasks associated to the specific skills of the TPACK framework, which roughly corresponds to technology-related self-efficacy (see Lachner et al., 2019a; Scherer et al., 2017 for critical discussion). This research has been shown that teachers' TPACK self-efficacy predict technology integration (Chuang, Weng, & Huang, 2015; Fraillon et al., 2019; Scherer, Siddiq, & Teo, 2015)

Perceived utility value

In addition to teachers' self-efficacy expectations in their ability to teach with technologies, their utility value of teaching with technologies, such as their attitudes and perceived usefulness of educational technologies, are regarded as further crucial barrier regarding technology integration (see Study 1, Chapter 6, p. 63; Scherer et al., 2017; Taimalu & Luik, 2019). Utility value describes the degree to which teachers perceive an added value of integrating technologies into their teaching, for example, to foster students' learning (see Study 1, Chapter 6 p. 63). Higher levels of utility value might incline teachers to integrate technologies more frequently during their teaching (Scherer et al., 2015).

8.1.3 Relations between self-efficacy, utility value and technology integration

However, whether and how teachers' self-efficacy and utility value interact and (differently) affect technology integration is yet unclear. This could be since a comprehensive framework is missing, as most research on technology integration was based on divergent, mostly independent lines of theoretical assumptions. Research on teachers' technology integration can be conceptualized as research based on Expectancy-Value Theory (EVT, Eccles & Wigfield, 2002) and as research based on technology acceptance models (TAM, Davis, 1989; Teo, 2011), which both have differential assumptions regarding the underlying mechanisms of teacher motivation on technology integration.

Expectancy-value theory

Most prominently, research investigating relations of individual motivational beliefs and associated behavior is summarized in the Expectancy-Value Theory (EVT; Eccles & Wigfield, 2002 for a summary of motivational belief models). The EVT states that an individual's expectancy of coping with a task (i.e., the self-efficacy and confidence in one's skills), and the utility value associated with the task (i.e., the perceived added value and usefulness of the task) determine the choice, persistence, and achievement within the task (i.e., technology integration). Most interestingly, the EVT considers teachers' self-efficacy and utility value to be side-by-side constructs that both have a simultaneous direct effect on technology integration (i.e., *concurrent mechanism* of motivation on behavior, see Figure 17, 1A).

An empirical illustration of these assumptions can be found in the study by Wozney and colleagues (2006). In a cross-sectional study with 764 primary and secondary teachers, the authors investigated the relations of teachers' self-efficacy and perceived utility value on their technology integration. In line with expectancy value theory, the authors found that both, self-efficacy and utility value were directly related to their frequency of technology use. However, this theory-conform pattern could rarely be replicated in further studies, as often only self-efficacy (e.g., Taimalu & Luik, 2019) or utility value (see Study 1, Chapter 6 and Study 2, Chapter 7) predicted technology integration. For instance, Taimalu and Luik (2019) examined the impact of the motivation of teacher educators (N = 54) on their technology integration by means of a questionnaire. The authors showed that only technology-related self-efficacy had a direct effect on their technology integration, but not their utility value beliefs. Contrarily, Author (20xxa) investigated the relations of teacher motivation and quality of technology integration in a lesson-planning scenario. Here, the authors found that perceived utility value, but not self-efficacy predicted the quality of technology-enhanced lesson plans (see Author 20xxb for similar findings). Therefore, the extent to which teachers' utility value and self-efficacy directly influence their technology integration in a concurrent mechanism is still an open issue.

Technology acceptance models

Besides general motivational beliefs research which is more and more adopted in the context of investigating technology integration, there are specific models for describing teachers' behavioral intentions to integrate technologies and the frequency of technology use in the classroom (e.g., unified theory of acceptance and use of technology *UTAUT*, Venkatesh, Morris, Davis, & Davis, 2003; technology acceptance model *TAM*, Davis, 1989; Scherer & Teo, 2019; for an overview, see Taherdoost, 2018). These models assume a cascaded relation of direct and indirect effects of motivational variables on technology integration (Scherer et al., 2019). Within these models different aspects of teachers' motivational beliefs are summarized which are assumed to influence their behavioral intention to use technologies and technology integration following a cascade. In its core assumptions, TAM differentiates internal motivational variables, such as perceived utility of technologies, which are regarded to directly account for technology integration; additionally, TAM assumes external motivational variables, such as self-efficacy, which are only indirectly associated with technology integration via internal variables, such as utility value (Scherer & Teo, 2019; Teo, 2011, see Figure 17, 1B).

Scherer et al., 2019 tested such a cascade mechanism of teacher motivation on technology integration by means of a meta-analytic structural equation model, based on 114 studies. In line with TAM, they found that teacher motivation followed a cascade mechanism where, first, self-efficacy was linked to the core variables of the TAM model such as utility value, and, second, utility value was linked to the behavioral intention and technology integration. However, it has to be noted that in many primary studies within the TAM framework the direct link between use intentions and actual use was missing (Nistor, 2014; Scherer et al., 2019). For example, Teo (2009) examined direct relations of pre-service teacher motivation and behavioral intention and found direct links of, both, self-efficacy and utility value on their behavioral intention to use technologies. However, the author did not investigate potential relations with the actual technology integration. Therefore, in line with EVT, Author (20xxg) conclude that teachers' self-efficacy should be further investigated in terms of direct relations of self-efficacy and technology integration as it possibly serves as a direct barrier or enabler for their behavior.

Two worlds apart?

Overall, the expectancy-value theory and the technology acceptance model differ in their assumed mechanisms of motivational beliefs on technology integration (concurrent vs. cascade mechanisms) while referring to the same explanatory components of motivational beliefs as core variables: self-efficacy and perceived utility value. Although the EVT focuses on distinct behavior as outcome variable and the TAM traditionally focuses on behavioral intention, both lines of reasoning can be extended to examine the relations between teacher motivation (i.e., self-efficacy and utility value) and type of technology integration to foster distinct teaching and learning processes as well as to support students' digital literacy (see also Siddiq et al., 2016). However, there are mixed results and blind spots in both lines of theoretical reasoning which may require an integrated perspective with a synergism of both lines of research. The integration of the concurrent and cascade mechanism would lead to a model which not only assumes direct relations of teachers' self-efficacy and utility value on technology integration but would also acknowledge a cascade mechanism of self-efficacy and utility value, see Figure 17, 1C. Therefore, it may be suggested that rather than being mutually exclusive, the relation between teacher motivation and technology integration may both constitute paths of concurrent and cascade mechanisms.

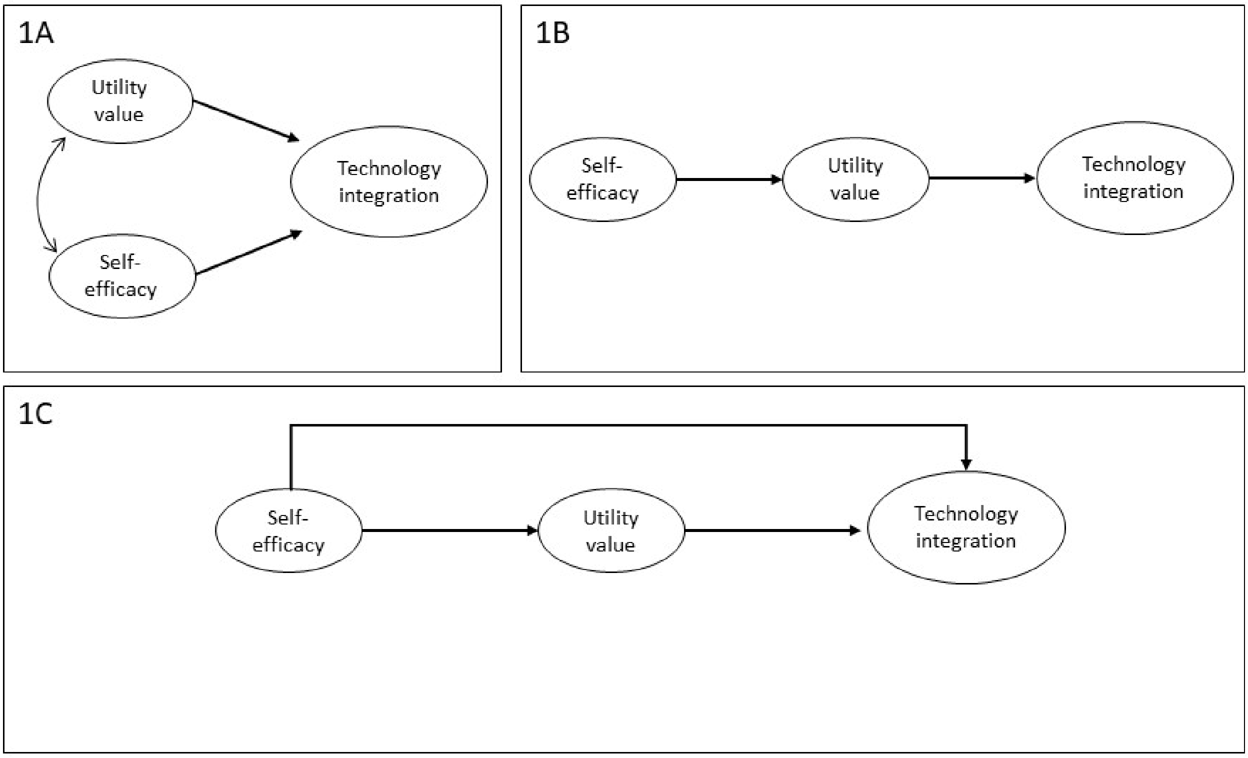

Figure 17. Schematic Representation of concurrent Mechanism (1A), cascade Mechanism model (1B) and Integration Model considering both Mechanisms (1C).

8.2 Present Study

We empirically tested the two different views on the assumed mechanisms of the relations between teachers' motivational beliefs and their technology integration to obtain differentiated insights into the nature of these mechanisms. Therefore, we first investigated the concurrent and cascade mechanisms of TPACK self-efficacy and utility value on technology integration. Second, we explored potential synergistic effects of concurrent and cascade mechanisms in an integrated perspective in which concurrent and cascade mechanism were combined. Addressing the key issues associated with the assessment of technology integration by only frequency-based measures, we measured teachers' emphasis on developing students' digital literacy next to the frequency of technology use during one-to-one teaching (Siddiq et al., 2016). We tested our assumptions using structural equation modelling.

The present study was conducted within a governmental initiative in Asker. Within this initiative all primary and lower secondary schools (grades 1-10, age of students: 6-16 years) in one municipality were equipped with technological infrastructure (i.e., tablets or laptops). Additionally, all participating teachers were enrolled in a professional development program. The present survey was conducted in 2017 at the start of the governmental initiative, meaning that all participating teachers already taught in actual one-to-one-classrooms, however, they were likely to possess relatively low levels of professional knowledge for technology integration given the little experience they had yet acquired with technology-based teaching.

8.2.1 Research questions

The context of the study allowed us to disentangle the divergent mechanisms (i.e., concurrent vs. cascade mechanism) of motivational beliefs on technology integration, as we had a unique technology rich research environment without external barriers such as lacking infrastructure. We operationalized technology integration, both in terms of the mere frequency of in-class technology use (*Research Question 1*), but also in qualitative terms of teachers' emphasis on developing students' digital literacy (*Research Question 2*). Besides testing concurrent versus cascade mechanisms, we explored the possible synergism between concurrent and cascade mechanisms in an integrated model. Please find a schematic representation of the assumed mechanisms in Figure 17. Specifically, we addressed the following research questions (RQs):

Research question 1: To what extent do teachers' TPACK self-efficacy and utility value explain variation in the frequency of in-class technology use in (a) a *concurrent mechanism*, (b) a *cascade mechanism*, and (c) an *integrated mechanism*?

Research question 2**:** To what extent do teachers' TPACK self-efficacy and utility value explain variation in the emphasis teachers put on developing students' digital literacy in (a) a *concurrent mechanism*, (b) a *cascade mechanism*, and (c) an *integrated mechanism*?

8.3 Method

8.3.1 Sample

All teachers (*N* = 730) who were part of the initiative received an invitation via e-mail with a link to the online survey. The participation in the survey was voluntarily and anonymous. $N_{initial}$ = 717 teachers (98 % participation rate) agreed to participate and started to fill in the survey. However, we excluded the data from 193 teachers, because either their responses on the TPACK self-efficacy and the utility value scales were completely missing and/or these teachers were not fully certified (e.g., librarians, assistant teachers). The final sample of the present study consisted of *N* = 524 in-service teachers (age: *M* = 45.25 years, *SD* = 11.05, teaching experience: *M* = 14.97 years, *SD* = 10.24).

8.3.2 Measures

Descriptive statistics and scale properties (e.g., mean, reliability, skewness) of our measures can be found in Table 12. All constructs that assessed the motivational beliefs as well as technology integration were represented as latent (unobserved) variables (Kline, 2016).

TPACK self-efficacy

An adapted and shortened version (Tondeur et al., 2017) of Schmidt et al.'s (2009) TPACK questionnaire was used to assess teachers' TPACK self-efficacy as, recently, these questionnaires have successfully been adopted to investigate multidimensional technology-related self-efficacy (e.g., Scherer et al., 2018). Therefore, teachers' self-efficacy of teaching with technology was assessed on four different dimensions: technological knowledge (TK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPCK). This short scale included 12 items. Teachers were asked to indicate their confidence in fulfilling tasks on the different dimensions of TPACK (e.g., TPK self-efficacy: "I can choose technologies that enhance the teaching approaches for a lesson."). A four-point Likert scale was administered that ranged from 0 (*strongly disagree*) to 3 (*strongly agree*).

Utility value

To assess teachers' perceived utility value of educational technologies, we applied a subscale of the attitudes towards educational technologies scale which was deployed in the ICILS 2013 study (Fraillon et al., 2014). The subscale consisted of 8 items which were found to capture value-related beliefs of educational technologies and to be positively related to technology integration (see Scherer et al., 2015; e.g., “Using technologies in school helps students work at a level appropriate to their learning needs”). A four-point Likert scale was administered that ranged from 0 (*strongly disagree*) to 3 (*strongly agree*) on which the teachers were asked to indicate their agreement.

***Technology integration*.**

*Frequency of in-class technology use***.** For the frequency of in-class technology use, we used a validated scale from ICILS 2013 (Fraillon et al., 2014; Siddiq et al., 2016) consisting of 11 different classroom scenarios (e.g., “I used technologies for presenting information through direct class instruction”, “I used technologies for providing feedback to students”). Teachers were asked to indicate how often they used technologies for each classroom scenario on a four-point rating scale from 0 (*never*) to 4 (*in every or almost every lesson*).

Emphasis on developing students’ digital literacy. To assess the teachers’ emphasis on developing students’ digital literacy during teaching, as a potential proxy for their inclination of teaching digital literacy, we administered the well-established TEDDICS scale, which consisted of 14 different items (Siddiq et al., 2016). With these items teachers were asked to rate the degree to which they emphasized the development of digital literacy skills in their teaching (e.g., “evaluating the credibility of digital information”, “exploring a range of digital resources when searching for information”; Fraillon et al., 2014; Siddiq et al., 2016). As these activities may not occur on a frequent basis during teaching, teachers’ were asked to assess the general emphasis on a scale from 0 (*no emphasis*) to 4 (*strong emphasis).*

8.3.3 Data analyses

Model estimation and evaluation

All manifest indicators of the latent variables were approximately normally distributed (see Table 12). To evaluate the fit of the structural equation models, we referred to established guidelines for an acceptable fit (i.e., CFI ≥ .95, TLI ≥ .95, RMSEA ≤ .08, and SRMR ≤ .10; Hu & Bentler, 1999; Kline, 2016). However, especially for complex factor structures with nested factors, these guidelines should not be considered as strict cut-off criteria, because they have been validated mainly for correlated-traits factor models (Marsh, Hau, & Wen, 2004). As suggested by Author (20xxf), we represented the factor structure of TPACK self-efficacy by a nested-factor model—specifically, we specified a bifactor-(S-1) measurement model (Eid, Geiser, Koch, & Heene, 2017). This bifactor structure of TPACK self-efficacy consisted of one general factor (indicated by all TPACK self-efficacy item responses) and four specific factors (each indicated by the specific items of the four TPACK dimensions TPK, TCK, TPCK, and TK). In this model, the specific factors co-vary, and one reference factor is chosen based on theoretical and conceptual reasoning (Eid et al., 2017; see Figure 18). We choose the Technological Knowledge (TK) factor as the reference, because it was found to co-vary less with all other TPACK-factors in previous studies (e.g., Scherer et al., 2017). As a consequence of setting this reference, all other specific factors represent the deviations from what is captured by the TK items. For a more detailed explanation of this procedure and the reasoning behind the interpretation of the resultant factors, we refer readers to Eid et al. (2017).

Additionally, we compared competing models by means of chi-square difference testing and by evaluating the differences in the goodness-of-fit indices next to the overall fit of the models. This was possible, as the two different models (concurrent and cascade mechanism models) differed in only one parameter (Kline, 2016) - the direct effect of self-efficacy on technology integration that only exists in the concurrent mechanism model. All models were specified and estimated using the R package *lavaan* (Rosseel, 2012).

Item parceling

Given that the models used to represent the constructs and their relations contained many parameters (due to the number of constructs involved and the bifactor structure) relative to the restricted sample size ($N = 524$), we used item parceling to effectively reduce the number of model parameters and, ultimately, describe the relations between motivational beliefs and technology integration with a more parsimonious model. As item parceling reduces the number of model parameters, statistical power and reliability are gained (Little, Cunningham, Shahar, & Widaman, 2002; Little, Rhemtulla, Gibson, & Schoemann, 2013; Rieger et al., 2019). We followed suggestions by Little et al., (2013) and built the item parcels summarized in a “super-item” through averaging the item response scores based on factor loadings of each item. First, the item with the highest factor loadings was selected; second, the one with the lowest factor loading was selected. These two items were then averaged, and a new variable (i.e., the item parcel) was created representing the mean responses across the two chosen items (see also Little et al., 2002). This procedure was then repeated for the next parcel. Following the suggestions by Little et al. (2013) and Matsunaga (2008), we built three parcels for each scale. To fulfill this requirement, two to five items were averaged into one parcel depending on the number of items of the scale. This approach allowed to reduce the number of model parameters and at the same time retain the relation among the structural parameters (Little et al., 2013). Moreover, this procedure allowed to avoid arbitrary item-item residual covariances, and, at the same time improve model fit and convergence (Little et al., 2013; Matsunaga, 2008). At the same time, we acknowledge that the use of item parcels is not unproblematic, especially when testing for the invariance of model parameters across groups (Marsh, Lüdtke, Nagengast, Morin, & von Davier, 2013). We therefore compared the results of our analyses between the models with item responses and item parcels as indicators of the latent variables (see Supplementary Material).

Handling missing data

As the in-service teachers (N = 524) participated in the study on a voluntarily basis in addition to their daily obligations, missing data occurred. In total, 6 % of the item responses were missing. Given that no pattern of missingness surfaced, we assumed a missing-at-random mechanism and performed full-information-maximum-likelihood (FIML) estimation. This procedure takes into account all available information (i.e., also participants with missing values) when estimating the model parameters (Enders, 2010).

Measurement models of teacher motivation

First, we specified and estimated the measurement models for TPACK self-efficacy and utility value. For *TPACK self-efficacy* and the item parcels as indicators (as described in section 3.3.1), we first specified a correlated-traits model distinguishing between the four TPACK aspects as separate but correlated factors (TCK, TPK, TPCK, and TK). The model exhibited an acceptable fit to the data, $\chi^2(48) = 107.504$, $p < .001$, RMSEA = .050, 90 % CI RMSEA = [.037, .062], CFI = .989, TLI = .985, SRMR = .025. Factor loadings in this model were high and ranged between .82 and .96. However, the correlations among some of the factors were as high as $\rho = .87$ (between the TCK and TCK factor). Second, we specified the bifactor-(S-1) model and obtained a well-fitting measurement model, $\chi^2(42) = 79.230$, $p < .001$, RMSEA = .042, 90 % CI RMSEA = [.028, .056], CFI = .993, TLI = .989, SRMR = .019. The general factor as well as its specific dimensions could be identified statistically through significant factor loadings (see Supplementary Material). Comparing the correlated-traits and bifactor(S-1) models showed the preference of the latter over the former, $\Delta\chi^2(6) = 28.275$, $p < .001$, ΔCFI = .004, ΔRMSEA = -.008, ΔSRMR = -.006. We therefore accepted the bifactor(S-1) model as a representation of TPACK self-efficacy in all subsequent analyses.

For *utility value,* we created three item parcels—hence, the final measurement model exhibited an exact fit to the data without any degrees of freedom in the model (for more details on this general observation, please refer to Kline, 2016).

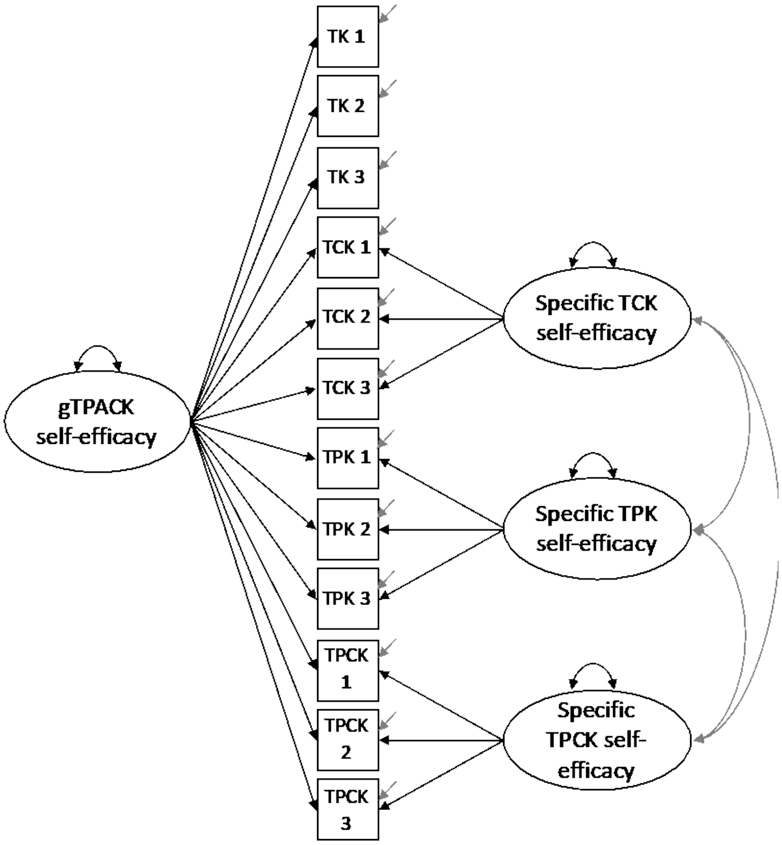

Figure 18. Bifactor(S-1) Structure of Teachers' TPACK Self-Efficacy

8.4 Results

8.4.1 Preliminary analyses

Descriptive statistics and scale reliabilities

First, we examined the descriptive statistics, characteristics of distributions, and reliability for each scale (see Table 12). Teachers' frequency of in-class technology use showed mediocre means indicating that teachers rather integrated technologies on average 'in some' to 'in most lessons' with huge differences among them as indicated by a high standard deviation. As the item distributions and scale distributions were neither severely skewed nor biased by ceiling effects, models that assume normally distributed latent variables could be specified. Cronbach's alpha showed acceptable to excellent reliabilities of the scales after one modification in the TPK scale (one item was deleted which was related to the self-efficacy of applying strategies which were learned during teacher education on how to teach with technologies; see Table 12).

The bivariate correlations showed that all investigated constructs were significantly correlated except for teachers' utility value and the emphasis they put on developing students' digital literacy (see Table 13). Given the high correlations between the specific factors in the TPACK self-efficacy measurement model (ranging between $\rho = .53$ and $\rho = .77$; see Supplementary Material), which may bias the structural parameters (i.e., path coefficients) in the subsequent models with utility value, technology use, and emphasis on developing students' digital literacy, we examined the extent to which the issue of multicollinearity occurred. The resultant variance inflation factors for each of the specific TPACK factors, the general TPACK factor, and utility value ranged between 1.22 and 3.28, indicating multicollinearity did not severely bias the structural parameters (criterion: VIF < 5; Thompson, Kim, Aloe, & Becker, 2017).

Table 12

Scale	*M*	*SD*	*N*	*Mdn*	*Min*	*Max*	Skewness	Kurtosis	*SE*	α
Utility value	2.073	.376	475	2.000	0.88	3.00	.289	.395	.017	.818
TPCK self-efficacy	1.811	.564	455	2.000	0.00	3.00	-.275	1.181	.027	.896
TCK self-efficacy	2.118	.531	484	2.000	0.00	3.00	-.154	1.341	.024	.924
TPK self-efficacy	1.803	.498	473	1.750	0.00	3.00	.037	.997	.023	.827
TK self-efficacy	1.682	.618	464	1.714	0.00	3.00	.192	.072	.029	.920
Frequency of technology use	1.105	.503	429	1.000	0.00	3.00	.796	1.208	.024	.876
Teachers' emphasis on developing digital literacy	1.582	.712	426	1.712	0.00	2.93	-.687	-.167	.034	.948

Descriptive Statistics and Scale Properties

Note. TPCK = Technological pedagogical content knowledge, TCK = Technological content knowledge, TPK = Technological pedagogical knowledge, TK = Technological knowledge; α = Cronbach's alpha.

Table 13

Bivariate Correlations among the Measures

	1	2	3	4	5	6
1 Frequency of technology use						
2 Teachers’ emphasis on developing students’ digital literacy	.564**					
3 Utility value	.249**	.099				
4 TCK self-efficacy	.300**	.218**	.276**			
5 TPK self-efficacy	.404**	.293**	.311**	.618**		
6 TPCK self-efficacy	.372**	.275**	.366**	.650**	.758**	
7 TK self-efficacy	.400**	.295**	.380**	.550**	.587**	.597**

** $p < .001$.

8.4.2 *RQ 1*: Teacher motivation and frequency of technology use

RQ 1a: Concurrent mechanism of teacher motivation on the frequency of technology use

First, we examined the concurrent mechanism of TPACK self-efficacy and utility value on frequency of in-class technology use. Therefore, we implemented the bifactor(S-1) model of TPACK self-efficacy and the measurement model of utility value as separate predictors of the frequency of technology use (see Figure 19). The model fit was excellent, $\chi^2(114) = 153.431$, $p = .008$, CFI = .994, TLI = .992, RMSEA = .026, 90 % CI RMSEA [.014, .036], SRMR = .021. We found that self-efficacy of technology-enhanced teaching (general TPACK self-efficacy: $\beta = .514$, *SE* = .083, $p < .001$, specific TPK self-efficacy, $\beta = .324$, *SE* = .155, $p = .036$) as well as their utility value ($\beta = .147$, *SE* = .073, $p = .044$) were directly related to the frequency of technology use. The two predictors explained 22.5 % of the variance in technology use. This finding indicates that, in line with expectancy-value theory, self-efficacy *and* utility value both were concurrently (i.e., directly) related to the frequency of in-class technology use.

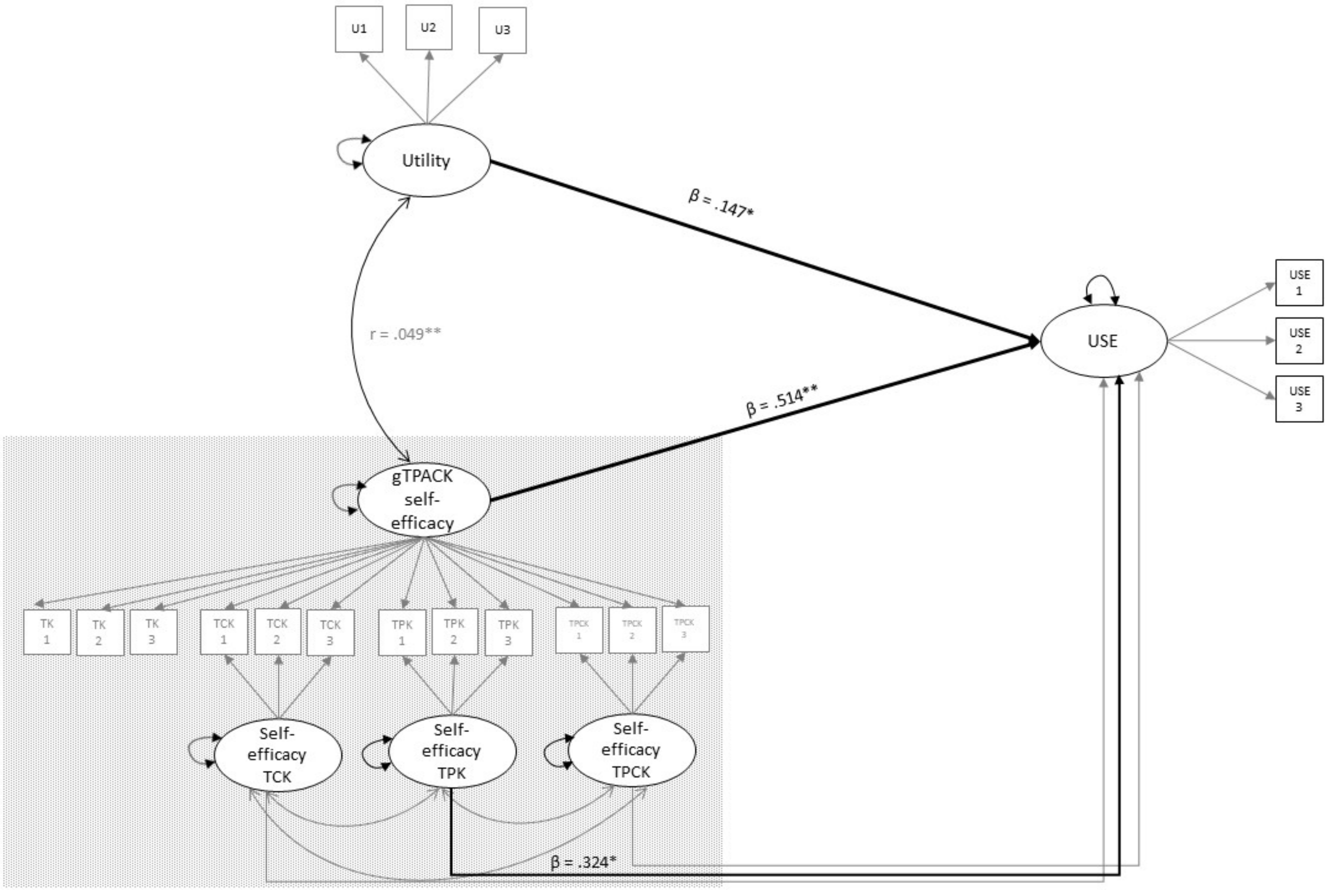

Figure 19. Concurrent Mechanism Model of Teachers' Self-Efficacy and Utility Value on Frequency of Technology Use.

Note. Bold lines represent statistically significant paths. The measurement model of TPACK self-efficacy is shaded in grey. * *p* < .05, ** *p* < .01.

RQ 1b: Cascade mechanism of teachers' motivation on the frequency of technology use

To model the cascade mechanism proposed in the technology acceptance model, we only allowed for the a cascaded/indirect effect of TPACK self-efficacy on technology use via their utility value (i.e., self-efficacy → utility value → frequency of technology use, Figure 20). The indirect effects were estimated by using 100 bootstrap samples. This model also showed the hypothesized path, following a cascade with a significant positive relation between self-efficacy of technology-enhanced teaching and utility value towards technology use (general TPACK self-efficacy: β = .482, *SE* = .063, *p* < .001; specific TPK: β =.217, *SE* = .098, *p* = .027). Utility value (β = .431, *SE* = .077, *p* < .001) was also positively related to the frequency of technology use. Additional mediation analysis revealed that this cascaded (indirect) effect was indeed significant (general TPACK self-efficacy: *a* × *b* = .208, bootstrapped *SE* = .049, *p* < .001, specific TPK self-efficacy: *a* × *b* = .094, bootstrapped *SE* = .054, *p* = .080). The total effect was

$\beta = .289$, bootstrapped $SE = .074$, $p < .001$. The overall model fit was reasonable ($\chi^2[118] = 208.976$, $p < .001$, CFI = .987, TLI = .983, RMSEA = .038, 90 % CI RMSEA [.030, .047], SRMR = .086), and 11.1 % of the variance in technology use were explained. Thus, our analyses also showed evidence for the cascade mechanism model based on the technology-acceptance model (TAM); yet, with a poorer model fit than the concurrent mechanism model, $\Delta\chi^2(4) = 55.545$, ΔCFI = -.007, ΔRMSEA = .012, ΔSRMR = .065.

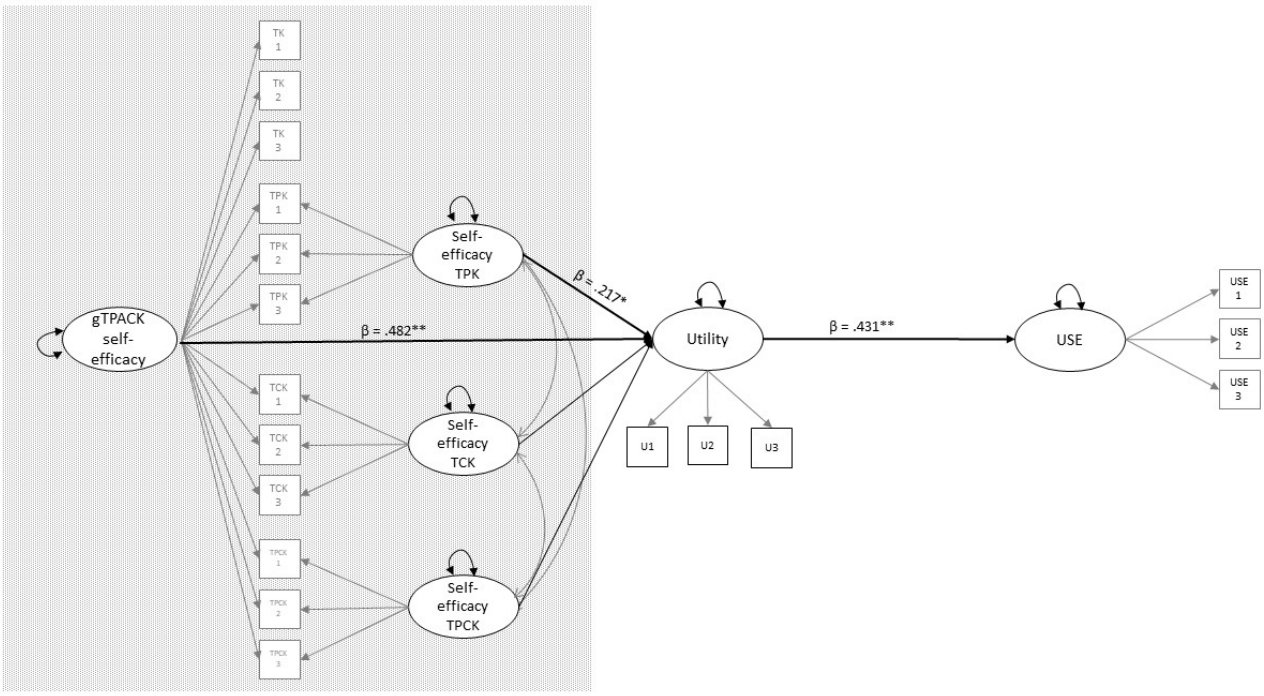

Figure 20. Cascade Mechanism Model of Teachers' Self-Efficacy and Utility Value on Frequency of Technology Use.

Note. Bold lines represent statistically significant paths. The measurement model of TPACK self-efficacy is shaded in grey. * $p < .05$, ** $p < .01$.

RQ 1c: Integrated perspective

The previous analyses provided evidence supporting the fit of both the concurrent- and the cascade-mechanism models. However, the overall model fit of the concurrent mechanism model (based on the EVT) was significantly better than for the cascade mechanism model (based on TAM). This was also supported by means of chi-square difference testing, as we found a significant better fit for the concurrent mechanism model than for the cascade mechanism model, $\Delta\chi^2(4) = 55.545$, ΔCFI = -.007, ΔRMSEA = .012, ΔSRMR = .065. This analysis indicated that, indeed, including the direct effects of TPACK self-efficacy on technology use was key to improving model fit. However, part of the variance of the frequency of technology use was still explained by an indirect effect of self-efficacy via utility value. Therefore, we built an integrated model encompassing direct and indirect paths of self-efficacy on the frequency of technology use and direct paths of utility value on the frequency of technology use (see Figure 17, 1C for a schematic overview). This integrated model enabled us to see whether the indirect effect of self-efficacy via utility value remained significant after allowing for the direct relation between self-efficacy and technology use. The direct relations between utility value ($\beta = .147$, $SE = .073$, $p = .044$) and technology use as well as the direct relations between TPACK self-efficacy and technology use were statistically significant (general TPACK self-efficacy: $\beta = .514$, $SE = .083$, $p < .001$, TPK self-efficacy: $\beta = .324$, $SE = .155$, $p = .036$). An additional mediation analysis showed that the general TPACK self-efficacy still had an indirect effect ($\beta = .068$, bootstrapped $SE = .037$, $p = .068$) on technology use (see Figure 21). The integrated model had an excellent fit, which was, due to the same covariance-matrix of the two models, exactly the same as the model fit of the concurrent model, $\chi^2(114) = 153.431$, $p = .008$, CFI = .994, TLI = .992, RMSEA = .026, 90 % CI RMSEA [.014, .036], SRMR = .021. Overall, 22.5 % of the variance in technology use were explained.

However, the integrated model did not only consider a relation between self-efficacy and utility value, but also encompassed the direction of the relation of self-efficacy and utility value following a cascaded trend. Additional nesting and equivalence testing (NET, Bentler & Satorra, 2010) showed that the integrated model had the equivalent complexity as the concurrent model (see Supplementary Material).

Overall, our findings showed that both hypotheses on the mechanisms of relations between TPACK self-efficacy, utility value, and the frequency of technology use could be supported. At the same time, the model comparisons indicated that a direct relation between TPACK self-efficacy and technology existed—this observation suggests that self-efficacy cannot only be considered an external variable which operates indirectly through utility value (as proposed in the TAM) but also a variable with a direct explanatory connection to technology use.

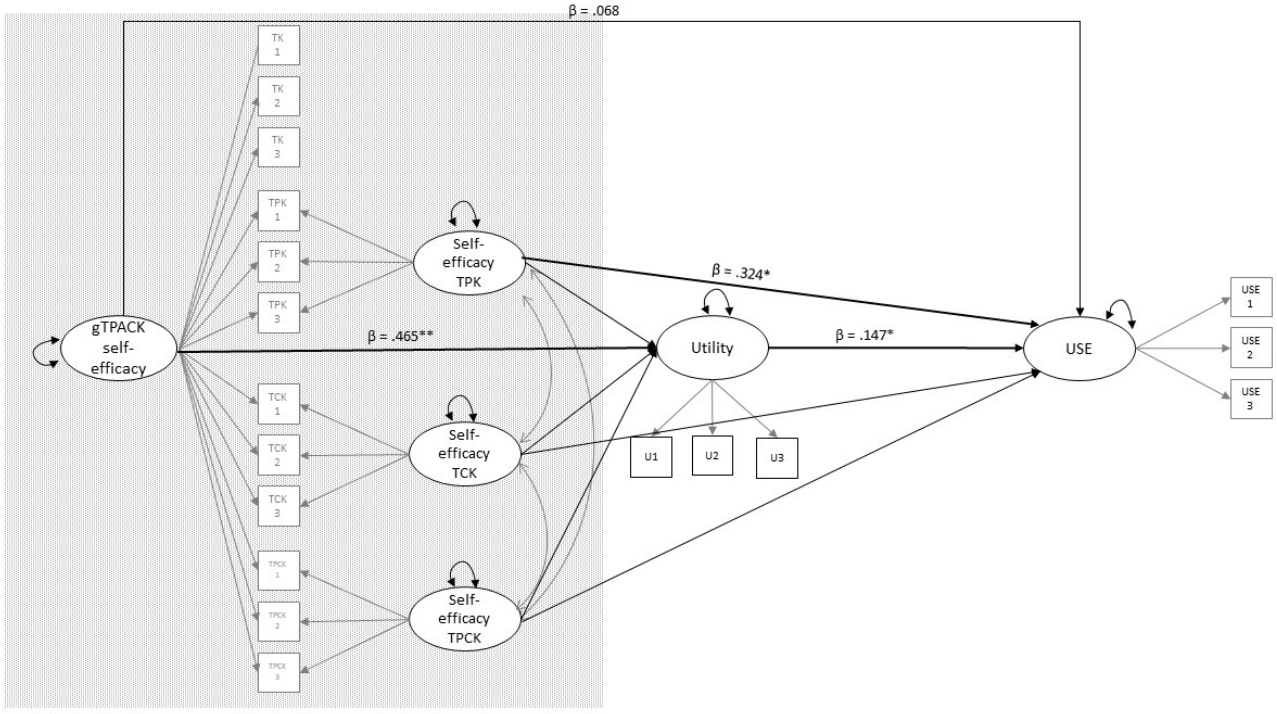

Figure 21. Integrated Model of Teachers' Self-Efficacy and Utility Value on Frequency of Technology Use.

Note. Bold lines represent statistically significant paths. The measurement model of TPACK self-efficacy is shaded in grey. * $p < .05$, ** $p < .01$.

8.4.3 *RQ 2*: Teacher motivation and emphasis on digital literacy

RQ 2a: Concurrent effect mechanism of motivation on emphasis. Regarding teachers' emphasis on developing students' digital literacy as outcome variable the analysis showed that only the direct paths of TPACK self-efficacy on emphasis was significant (see Figure 22). More specifically, general TPACK (β = .633, *SE* = .122, *p* < .001) and TPK (β = .459, *SE* = .234, *p* = .050) self-efficacy were significantly related to teachers' emphasis on developing students' digital literacy, while no significant direct effect of utility value on their emphasis was obtained (β = -.042, *SE* = .110, *p* = .701). The fit of the underlying model was very good, $\chi^2(114) = 165.323$, *p* = .001, CFI = .993, TLI = .991, RMSEA = .029, 90 % CI RMSEA [.019, .039], SRMR = .026. This analysis indicated that self-efficacy of teaching with technology was directly related to the emphasis teachers' put on developing their students' digital literacy—however, their utility value was not directly related. Therefore, the assumed concurrent mechanism based on the EVT could only be partly confirmed. Overall, 11.6 % of the variance in the outcome variable could be explained.

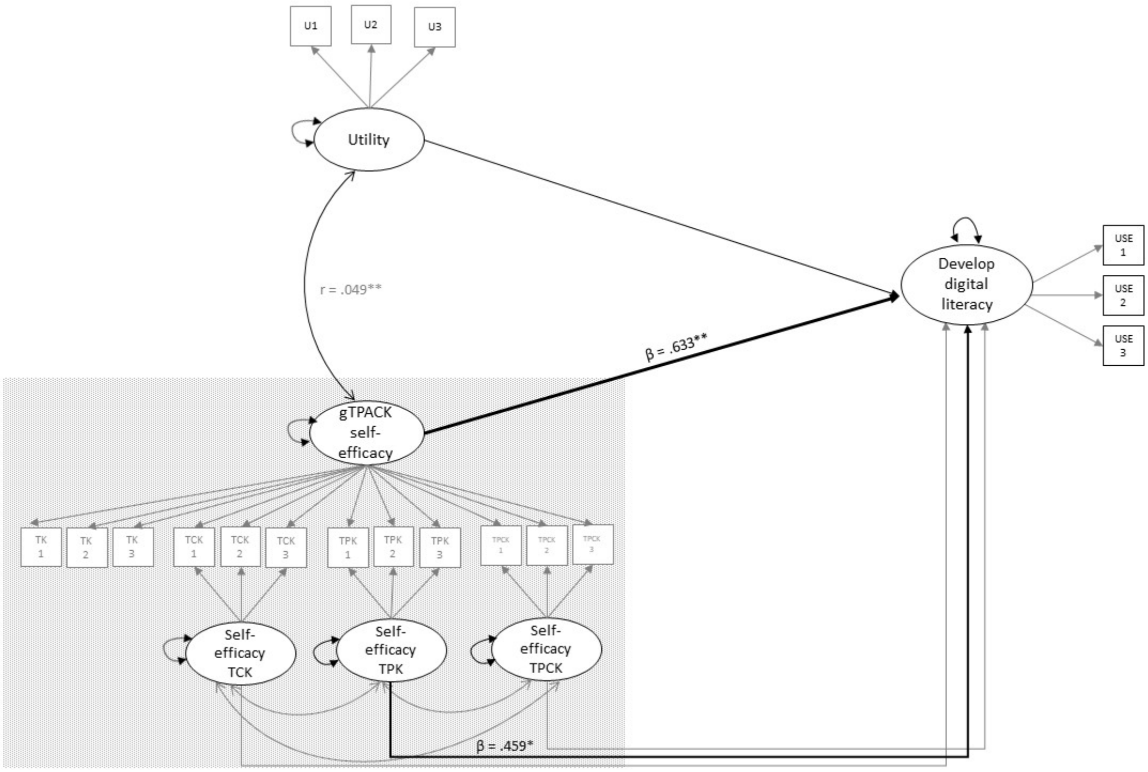

Figure 22. Concurrent Mechanism Model of Teachers' Self-efficacy and Utility Value on Teachers' Emphasis on developing Students' Digital Literacy.

Note. Bold lines represent statistically significant paths. The measurement model of TPACK self-efficacy is shaded in grey. * $p < .05$, ** $p < .01$.

RQ 2b: Cascade effect mechanism of motivation on emphasis. To model the cascade mechanism proposed in the technology acceptance model, we only allowed for the indirect effect of TPACK self-efficacy on their emphasis on developing students' digital literacy (see Figure 23). Again, the general TPACK self-efficacy factor and the specific TPK factor were positively related to utility value (general TPACK self-efficacy: β = .473, *SE* = .060, $p < .001$; specific TPK self-efficacy: β = .214, *SE* = .118, $p = .069$). Furthermore, perceived utility (β = .307, *SE* = .096, $p = .001$) was positively related to the emphasis teachers put on developing students' digital literacy skills. An additional mediation analysis showed that this cascaded effect was indeed significant (general TPACK self-efficacy: β = .145, bootstrapped *SE* = .053, $p = .006$). The total effect was β = .202 (bootstrapped *SE* = .071, $p = .005$). The model fit was slightly worse than in the concurrent model, $\chi^2(118) = 204.032$, $p < .001$; CFI = .988, RMSEA = .037, 90 % CI RMSEA [.029, .046], SRMR = .084, suggesting that it is important to consider the direct effects of TPACK self-efficacy on the emphasis they put on developing students' digital literacy, which are proposed in the EVT. Overall, 2.5 % of the variance in emphasis they put on developing students' digital literacy could be explained, while 21.8 % of the variance in utility value were explained.

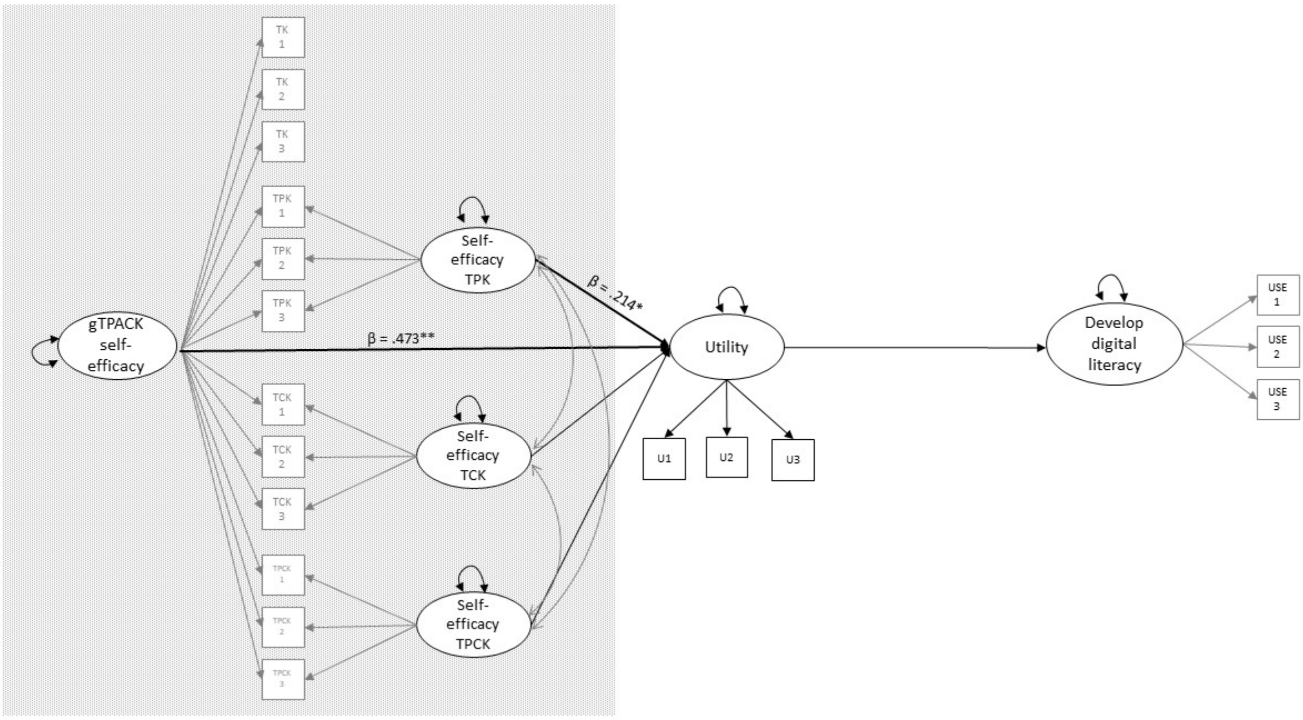

Figure 23. Cascade Mechanism Model of Teachers' Self-Efficacy and Utility Value on Teachers' Emphasis on developing Students' Digital Literacy.

Note. Bold lines represent statistically significant paths. The measurement model of TPACK self-efficacy is shaded in grey. * $p < .05$, ** $p < .01$.

RQ 2c: Integrated perspective. Again, already the evaluation of the overall model fit indicated that the concurrent mechanism model represented the data better than the cascade mechanism model. This was also supported by means of chi-square difference testing as it showed a significant better fit for the concurrent mechanism model, $\Delta\chi^2(4) = 38.709$, $p < .001$, $\Delta CFI = -.005$, $\Delta RMSEA = .008$, $\Delta SRMR = .058$. Additionally, we build an integrated model encompassing direct and indirect effects of self-efficacy and direct effects of utility value on the emphasis of developing students' digital literacy (see Figure 17, 1C for a schematic overview; see Figure 24 for the detailed model parameters). In line with the considerable better model fit of the concurrent model, the model fit of the integrated model was very good, and again the same as in the concurrent model as the covariance matrix of the integrated model was the same as in the concurrent model $\chi^2(114) = 165.323$, *p* = .001; CFI = .993, RMSEA = .029, 90 % CI RMSEA [.019, .039], SRMR = .026. Accordingly, both models were equally complex (Bentler & Satorra, 2010). The model showed direct relations between self-efficacy for technology-enhanced teaching and the emphasis on developing students’ digital literacy (general TPACK self-efficacy: β = .633, *SE* = .122, *p* < .001, specific TPK self-efficacy: β = .459, *SE* = .234, *p* = .050). Additionally, general TPACK self-efficacy was related to the utility value (β = .465, *SE* = .060, *p* < .001). However, there were no indirect effects of self-efficacy on teachres’ emphasis on developing students’ digital literacy and, in line with that, no significant total effect (see Supplementary Material). This model resulted in a variance explanation of 11.5 % in the final outcome variable and 21.2 % in utility value.

Overall, the analysis suggests that self-efficacy is directly related to their emphasis on developing students’ digital literacy and therefore most important whereas their utility value is not. In addition, there were no indirect relations of self-efficacy and teachers’ emphasis on developing students’ digital literacy.

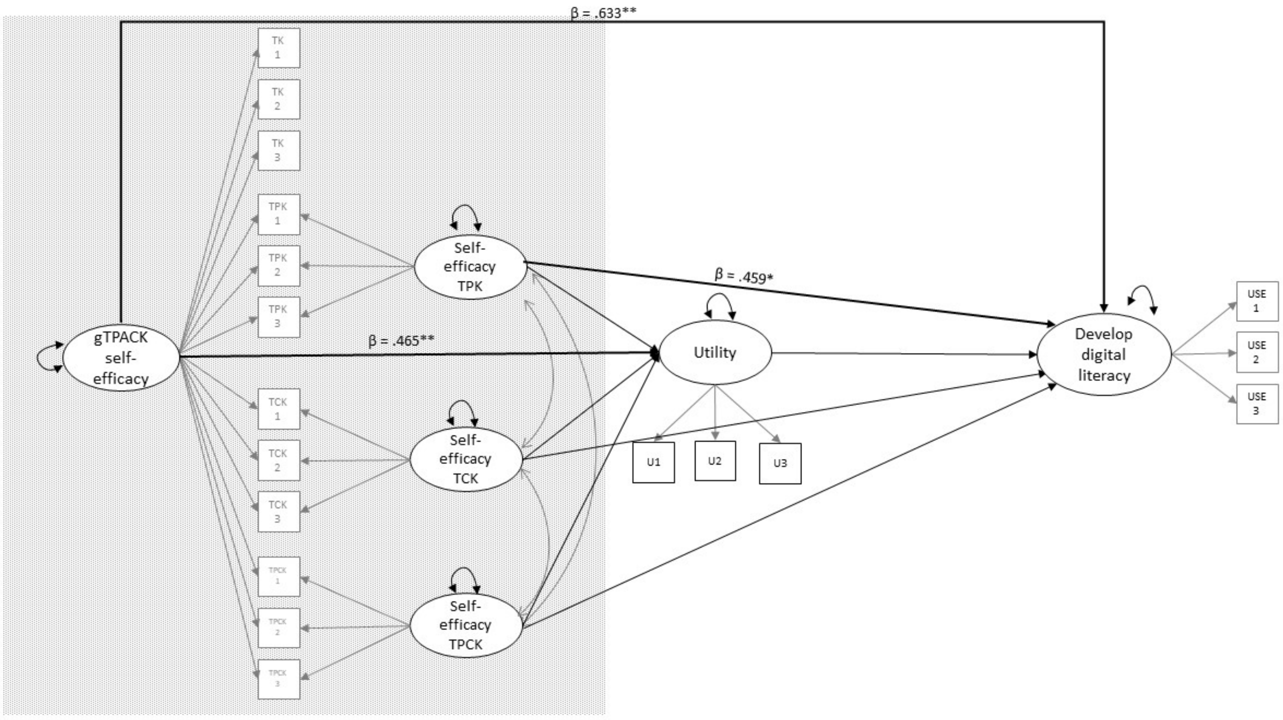

Figure 24. Integrated Model of Teachers’ Self-Efficacy and Utility Value on Teachers’ Emphasis on developing Students’ Digital Literacy. *Note.* Bold lines represent statistically significant paths. The measurement model of TPACK self-efficacy is shaded in grey.

* *p* < .05, ** *p* < .01.

8.5 Discussion

The present study investigated relations between teacher motivation and their technology integration (measured as frequency of technology use and teachers' emphasis on developing students' digital literacy) in a unique technology-rich environment. We followed two divergent perspectives which either assumed (a) a concurrent mechanism of TPACK self-efficacy and utility value based on expectancy-value theories (EVT) or (b) a cascade mechanism following technology acceptance models (TAM).

Regarding the frequency of in-class technology use, structural equation modelling revealed that the concurrent and the cascade model represented the data well. Based on additional model comparison tests, we found that an integrated model encompassing direct and indirect relations of self-efficacy, utility value and the frequency of technology use may best represent our data. Therefore, when teachers get started with using technologies for teaching, self-efficacy may have a direct effect and an indirect effect via utility valued on their frequency of technology use. Regarding teachers' emphasis on developing students' digital literacy, however, only TPACK self-efficacy were predictive. This suggests that for distinct (complex) teaching activities such as improving students' digital literacy skills it might be more important that teachers feel confident to implement these teaching activities. As such, these findings suggest that teachers' self-efficacy might be more than an external variable, as it has direct effects on their technology integration.

Additionally, the representation of TPACK self-efficacy in a bifactorial measurement model allowed us to disentangle differential effects of the different components of technology-related self-efficacy on their technology integration. This analysis showed that besides the relation of teachers' general self-efficacy regarding technology-enhanced teaching their self-efficacy of being able to integrate technologies in their pedagogical approaches (i.e., TPK self-efficacy) played a crucial role.

8.5.1 Theoretical contributions and implications

From a theoretical point of view, the present study extends current research within the EVT and the TAM framework, as our findings rather corroborate an integrated perspective on teacher motivation and technology integration, at least for the frequency of in-class technology use. This finding may resolve potential differences between previous studies (see Study 1, Chapter 6, p. 63 and Study 2, Chapter 7, p. 93; Scherer et al., 2019; Taimalu & Luik, 2019), as the integrated perspective suggests that direct and indirect relations of teacher motivation and technology integration may co-exist. Based on these analyses and in line with suggestions by Author (20xxg), in research on technology integration, self-efficacy should be taken more into account. Our findings indicate that self-efficacy is not only highly related to core TAM variables, such as perceived utility, but also directly influences the frequency of technology use and emphasis on developing students' digital literacy. Therefore, our findings suggest that the EVT and the TAM are not mutually exclusive to understand the relation between teacher motivation and technology integration. Hence, an integrated perspective should be adopted when investigating teachers' technology integration for fostering teaching and learning processes. This integrated perspective considers previous work of, both, research focusing on relations of motivational beliefs and individuals' behavior (e.g., EVT; Eccles & Wigfield, 2002) and research focusing on technology use and identifying potential boundary conditions for its use (e.g., TAM Scherer & Teo, 2019; Scherer et al., 2019). Consequently, research that follows the reasoning of motivational beliefs theory should also take into account that there are cascade effects and relations of teachers' self-efficacy and their attitudes about technologies. In the field of student motivation this lack of considering intervening effects of self-efficacy and utility value has been currently discussed (e.g., Nagengast et al., 2011; Trautwein et al., 2012), and should be transferred to research investigating direct relations of teacher motivation and their technology integration. Additionally, it might be useful for future research following the TAM reasoning to consider direct relations of self-efficacy and technology integration and therefore reflect that teachers' self-efficacy is an internal variable of their beliefs (Bandura, 2010). Overall, the present study can help to bridge the gap between the two worlds of theoretical reasoning to be able to design and implement the most effective teacher education programs for technology-enhanced teaching.

Furthermore, our study did not only investigate the mere frequency of in-class technology use, but also teachers' emphasis on developing students' digital literacy. An unexpected finding was that only self-efficacy, but not utility-value was related to teachers' emphasis on students' digital literacy. This finding stands in contrast to previous studies, which demonstrated that the perceived utility was decisive for related yet distinct quality indicators, such as technology exploitation, or general teaching quality (see also Study 1, Chapter 6, p. 63 and Study 2, Chapter 7, p. 93). The unexpected pattern can be explained in three ways: First, the applied outcome measure was focused on the development of students' digital literacy and not, as in the studies by Author (20xxa, 20xxb) on subject-specific teaching quality. Therefore, it might be the case, that teachers need high utility value to implement technology in a pedagogical meaningful manner, however, particularly, one's self-efficacy may be important to be a role model and put distinct emphasis on students' digital literacy, and not only see technology as a tool to foster teaching (Tondeur et al., 2020). Second, in the present study we assessed teachers' utility value based on their perceived added value of introducing technologies related to students' academic performance and motivation (e.g., "Using technologies in school, helps students to consolidate and process information more effectively", "Using technologies in school, helps students develop greater interest in learning"). However, the recently published study by Author (20xxa, 20xxb), additionally assessed utility value based on teachers' perception of the societal relevance of teaching with technologies (e.g., "I believe that a progressive introduction of technology into education responds to our society's changing needs.") which likely corresponds with the emphasis teachers' put on developing students' digital literacy. This should be further investigated in future studies. Third, we want to note that we only measured teachers' emphasis on digital literacy on the basis of self-reports, which may restrict the validity of our findings. Therefore, our findings should be replicated with more direct measures, such as classroom observations and recordings of classroom situations (see Koh, Chai, & Tay, 2014, for an example).

Finally, from a methodological perspective, a further contribution of our study is the assessment of self-efficacy for teaching with technologies in a very fine-grained manner based on the TPACK self-assessment questionnaire by Schmidt et al. (2009). This allowed us to apply bifactor(1-S)-models (Eid et al., 2017), which modeled self-efficacy on different dimensions, and at the same time allowed to model general technology-related self-efficacy. Therefore, we were able to represent the complex and multidimensional structure of the different dimensions of self-efficacy and to disentangle differential relations of the subdimensions with technology integration. Such approaches may help to better understand potential effects of teacher motivation on technology integration (Scherer et al., 2019).

8.5.2 Practical contributions and implications

From a practical point of view, it is particularly interesting that even (or especially) in this technology-rich environment (i.e., one-to-one classrooms) teacher motivation was a crucial boundary condition for technology integration. This finding showed that technological infrastructure is only a necessary but not sufficient conditions for teachers' technology integration (see also Drossel et al., 2017). Therefore, policy makers and teacher educators should consider teacher motivation when introducing (governmental) initiatives for enhancing technical infrastructure at schools. More precisely, both the concurrent and cascade relations of teachers' motivational beliefs and their technology integration should be considered. Furthermore, teacher educators and teachers themselves should be aware that both, their beliefs about the self-efficacy and utility value of educational technologies, influence the amount and quality of technology integration.

For teacher educators it is particularly interesting that the self-efficacy of integrating technologies in a pedagogical meaningful way (i.e., TPK self-efficacy) plays an outstanding role. Therefore, teacher education programs should not only address technological knowledge on how to deal with technologies, but integrate this technological knowledge with pedagogical methods and technology-enhanced teaching practices. For example, this can be achieved by providing students with guided opportunities to use educational technologies already in early phases of teacher education (Grossman & McDonald, 2008; Lee & Lee, 2014; Seidel, 2006).

8.5.3 Limitations and future directions

The present study is a first attempt to integrate research based on EVT and TAM as two prominent theoretical approaches to model relations between teacher motivation and technology integration. However, we have to note that we only considered the core mechanisms of EVT and TAM. In addition, both theories account for further variables (e.g., cost as dimension in the EVT, see Flake, Barron, Hulleman, McCoach, & Welsh, 2015; subjective norms as dimension in the TAM, see Scherer et al., 2019), which may additionally constrain teachers' technology integration. Hence, we encourage researchers to take a closer look at additional variables presumably considered in these extended models. Besides a differentiated view on the constraining motivational beliefs also a closer look should be adopted with regard to teachers' technology integration. For example, it would be interesting to replicate the findings of the current study with data based on teachers' actual technology use during teaching, and apply more direct measures of teaching quality rather than assessing self-reported technology integration.

8.6 Conclusion

The main idea of the present study was to integrate two predominantly apart worlds to outline a comprehensive and integrated picture of teacher motivation and technology integration. The findings suggest that researchers of both fields can learn from each other to conclusively inform practice, policy makers and teacher educators. As such, future teachers can be “equipped” with the necessary motivational prerequisites to effectively integrate technology in their teaching.

9 GENERAL DISCUSSION

The use of technology for teaching is seen as crucial to provide students with the most effective learning environment to acquire conceptual knowledge across a variety of domains as well as to obtain digital literacy needed to fully participate in the 21st century (Fraillon et al., 2019; KMK, 2016; OECD, 2015). However, so far we know relatively little on how to effectively integrate technology in the classroom and on the boundary conditions that drive effective integration. Previous research examined rather distal indicators of technology integration, such as teachers' self-reported frequency of technology integration in surveys (e.g., ICILS 2013, 2018; Fraillon et al., 2019). Therefore, no comprehensive conceptualizations of technology-enhanced teaching quality or of the teachers' competencies for successful technology integration have been systematically developed in previous research. To address these research gaps, the present dissertation had four aims. The first aim was to develop a comprehensive conceptualization of how teachers integrate technology based on indicators derived from research on teaching quality and technology-enhanced learning (TEL). The second aim was to enable a fine-grained view on how technologies are currently applied within teaching by means of elaborate empirical approaches such as analyses of lesson plans, lesson documentations, and complex statistical modelling. The third aim was to conceptualize teacher competencies for technology-enhanced teaching (TET) based on generic models of teachers' professional competencies, recent descriptions of boundary conditions for technology integration, and, most importantly, the evidence provided in the present dissertation. The fourth aim was to examine the relative role of different components of teachers' competencies such as their professional knowledge and motivation and its relation to TET. To this end, teachers' TET-related competencies were assessed and related to their technology integration in diverse contexts and on different grain-levels.

In the present dissertation, therefore, the research field of technology-enhanced teaching was expanded in terms of theoretical and methodological aspects by adopting and empirically investigating generic models of teaching quality and professional competencies in the context of TET. The gained insights can ultimately inform educational practitioners such as teacher educators and policy makers.

9.1 Summary of Studies

In order to pursue the defined aims of the dissertation, three empirical studies were conducted. Each study set different emphases and applied different methods to shed light on the technology-enhanced teaching and the related professional competencies in a diverse and reliable way.

In Study 1, the impact of teachers' professional knowledge and motivation on the quality of technology-enhanced lesson plans as a function of their expertise was investigated ($N = 94$ teachers in mathematics varying in their relative expertise). Accordingly, first, a comprehensive conceptualization was established which presents aspects of good-quality technology-supported teaching in mathematics. This conceptualization has been developed on the basis of research on generic and specific mathematics-related teaching quality and insights from research on technology-enhanced learning. Second, this conceptualization was applied to analyze the quality of lesson plans. The analyses showed that advanced teachers (i.e., trainee and in-service teachers) provided higher quality lesson plans than novice teachers (pre-service teachers; RQ1). Further examinations revealed that not teachers' professional knowledge (content knowledge, pedagogical content knowledge, and technological knowledge) but their motivational beliefs (TPACK self-efficacy, utility value) and in particular their utility value were crucial for the quality of the lesson plans. Utility value mediated the effect of expertise on instructional quality and technology exploitation (RQ2). To investigate if these relations are also present in authentic teaching situations and stable across contexts, two subsequent studies were conducted.

In Study 2, it was addressed how teachers' motivation and their technology integration are related and vary in authentic in-class technology use across subjects and lessons ($N = 18$ in-service teachers). Therefore, the conceptualization of technology integration of Study 1 was extended to be applied to lesson documentations across different subjects. The mixed-method analyses revealed that teacher motivation, frequency, and quality of technology integration varied considerably across lessons (RQ3). The variability could be explained by the relations between technology-related value beliefs, specific factors within the different instructional contexts, and technology integration (RQ4). The findings emphasize the importance of teachers' utility value and therefore support the results of Study 1 and additionally highlight the role of contextual aspects in teachers' technology integration.

To investigate the relation of teacher motivation and technology integration in a different educational system, in Study 3 survey data from Norwegian in-service teachers were analyzed (N = 524). This large sample enabled a very differentiated view on teacher motivation and its associated technology integration. Structural equation modeling showed that concurrent mechanisms based on expectancy-value theory and cascade mechanisms based on technology acceptance models of self-efficacy and utility value were both suited to explain the frequency of technology integration. Therefore, the findings indicate that rather than being mutually exclusive, the two perspectives should be integrated (RQ5). Such an integrated perspective on teacher motivation in the context of technology integration appears more reasonable to inform research and practitioners about the relationships between teacher motivation and technology integration.

The three studies with their different empirical approaches and emphases addressed the four aims from different perspectives. The first aim of developing a comprehensive conceptualization of how teachers integrate technology was primarily addressed in Study 1 and Study 2. This aim was achieved by developing a conceptualization based on indicators derived from research on teaching quality (Hugener et al., 2009; Klieme et al., 2001) and technology-enhanced learning (e.g., multimedia research; Li et al., 2019; Moreno & Mayer, 2007; Renkl & Scheiter, 2017) and the findings from the empirical studies of the present dissertation. Accordingly, the conceptualization was initially applied to lesson plans in mathematics and then broadened to lesson documentations across subjects. The resulting conceptualization encompasses generic aspects of technology integration, such as frequency and digital literacy, as well as specific aspects to change the product of teaching, such as the teaching methods and the teaching and learning processes, through technology integration (see Chapter 9.4.1). The second aim was to enable a fine-grained view on teachers' technology integration. This aim was achieved by applying diverse and innovative empirical approaches such as lesson plan analyses, experience-sampling approaches, and mixed-model analyses in the different studies. These investigations showed that teachers used technologies relatively often, however, as suggested in the literature, did not utilize the full potentials offered by the technologies (see Chapter 9.2). Therefore, the third aim was to conceptualize the teachers' competencies for technology-enhanced teaching (TET) to depict potential enablers for technology integration. This aim was achieved by investigating systematically the relation of teachers' competencies, namely their professional knowledge and motivation, and technology integration. The findings of the present dissertation suggest a comprehensive conceptualization of teachers' competencies with a focus on teacher motivation (see Chapter 9.4.2). The crucial role of motivation became particularly evident when examining the fourth aim, the relative role of teachers' professional knowledge and motivation in Study 1. In this regard, it is especially remarkable that utility value was dominantly related to technology integration across all study approaches and contexts (see Chapter 9.3).

In summary, the present dissertation offers a comprehensive conceptualization of both aspects of good-quality technology-enhanced teaching and teachers' professional competencies for technology integration. A particular strength of the dissertation was that these conceptualizations were investigated with different empirical approaches which allowed for different perspectives on the relation of teachers' competencies and their technology integration. Across studies, the analyses revealed that teachers' utility value is crucial for their technology integration. Therefore, the resulting overall approach of the present dissertation meets the current need for replication in science, especially in psychology and related social sciences (see e.g., Maxwell, Lau, & Howard, 2015, for discussion on replication crisis in psychology).

9.2 Technologies were used, but not exploited

The diverse methodological approaches of the present dissertation provided insights into teachers' technology integration from different perspectives and at several resolution levels. In particular, these approaches allowed for the investigation of how often and in what manners technologies are currently applied. Additionally, the studies were conducted in various contexts, namely in regular schools with average technical equipment and in schools with one-to-one equipment in Germany, and in schools with one-to-one equipment in Norway. Therefore, when accumulating the findings of the different studies a comprehensive picture on technology integration can be depicted.

Study 2 and Study 3 of the present dissertation allowed for the investigation of teachers' technology integration frequency. Across these studies, the teachers' *frequency of technology integration* was rather high in contrast to frequencies reported in other studies such as ICILS (Fraillon et al., 2019). This can be attributed to the technology-rich contexts in which the present studies took place. However, analyses of the type of technologies used in the studies of the present dissertation showed that predominantly simple applications were used. In line with the self-reports captured in ICILS 2018 (Fraillon et al., 2019), teachers mainly used presentation tools and text reader software. However, the type of technologies used varied largely across teachers and also across different lessons of a single teachers (see Study 2). Whereas in some lessons only presentation tools were used, in other lessons the teachers used more advanced applications such as virtual simulations and feedback tools. Therefore, the findings showed that some teachers indeed used complex technological applications such as dynamic geometry applications (e.g., GeoGebra) to visualize the relations of a formula and its geometrical representation. However, other applications that were found to be very effective for learning such as audience response systems (Aleven et al., 2016; Olympiou et al., 2013; Zhu & Urhahne, 2018) were not very common in the present studies.

More important than the frequency and type of distinct hard- and software used during teaching, is *how* technologies were applied with regard to changing the products and processes of technology-enhanced teaching quality (Hamilton et al., 2016; Jonassen, 2005). The *change of the products* of teaching such as the teaching methods can be achieved by technology exploitation (Hughes et al., 2006; Puentedura, 2006). Technology exploitation indicates that the different potentials offered by the technologies and the different characteristics can be used to transfer and redefine teaching methods. This way, the sight structure of the teaching methods and how the appearance of these methods changed through technology use is investigated. In line with the rudimentary types of technologies used, the overall technology exploitation was rather low across the studies of the present dissertation. In particular, technologies were predominantly used to substitute and modify traditional teaching methods but not to establish transformative and innovative ways of teaching. Therefore, the distinct affordances of technologies to design the teaching methods in a new way such as adaptivity, multimodality, and interactivity (Ma et al., 2014; Moreno & Mayer, 2007) were not fully applied.

The *change of the processes* of teaching and learning through technology integration can be achieved by applying different aspects of high-quality teaching within the context of technology-enhanced teaching (Baumert & Kunter, 2006). Therefore, the generic categories for teaching quality of the *German framework of three basic dimensions* (Klieme et al., 2001; Praetorius et al., 2018) were applied: cognitive activation, instructional support, and classroom management. In this way it could be investigated to what extent technologies serve as cognitive tools that support the learning processes of students, as postulated by Jonassen (2005). The analyses of the lesson plans and lesson documentations revealed, however, that teachers struggled in establishing high-quality technology-enhanced teaching. The investigations of expertise differences showed that in-service teachers with more teaching experience outperformed pre-service teachers (see Study 1). The deliberate practice of in-service teachers potentially allowed them to incorporate an additional complexity by integrating technologies. However, even though in-service teachers were better able to establish high-quality teaching, there was room for improvement. This finding suggests that teachers need distinct support in integrating technologies into their teaching in a way that it fosters students' cognitive processes.

Together, a strength of the present dissertation is that the applied methods allowed, as one of the first empirical investigations, for a comprehensive and systematic view on how teachers use technologies during their teaching. The analyses of the lesson plans in Study 1 allowed for very differentiated analyses of the quality of the intended teaching methods and planned learning activities. Moreover, the scenario-based approach in mathematics allowed for a clear comparison across teachers. However, the questions were left open how teachers integrate technologies in their daily teaching practice and across subjects. Therefore, in Study 2 the teacher diary embedded in an experience sampling approach had the strength that it was possible to assess authentic lessons and several lessons of one teacher. These very fine-grained analyses of distinct lessons of German teachers was complemented by a survey study in Norway. This survey study allowed for the investigation of technology integration in a different context and in a more holistic manner. In sum, the teachers of the present studies used technologies relatively often, however, tended to not fully exploit their provided potentials to enhance teaching and learning processes. Therefore, these findings indicate that the infrastructure provided, for example in one-to-one initiatives, is only a necessary, but not sufficient condition for TET (see Drossel et al., 2017, for related findings). Furthermore, the findings suggest that teachers need distinct support to be able to integrate technologies meaningfully into their teaching. Therefore, future studies should investigate how teachers can be supported to use technologies in an elaborate way.

One limitation of the present investigation of TET was that, due to the focus on the concrete teaching and learning processes within the lesson plans and documentations, classroom management was not represented in the categories. To keep the teacher diary of Study 2 as concise as possible it was decided to provide only prompts that focus on learning objectives, teaching methods, and technology use during the lesson. However, teachers wrote in many lesson documentations about aspects of classroom management such as disruptions which was very valuable to get an inclusive impression of the lesson. In order to take the importance of classroom management into account, it was assessed in the teacher's diary by asking the teachers how smooth they perceived the course of their lesson. However, this self-reported classroom management might be biased. Therefore, in future studies, this item could be adapted to serve as an additional indicator for TET quality. This way, for example, the smoothness of the technology-enhanced lesson could be investigated to see how disturbances caused by the students or technological problems affect TET.

9.3 *Will* is crucial for TET

It is generally assumed that teacher competence is a crucial determinant for technology-enhanced teaching (Farjon et al., 2019; Knezek & Christensen, 2016; Petko, 2012). However, previous research did not investigate systematically the relations of the different aspects of teachers' competencies and their technology integration. To address this research gap, the studies of the present dissertation were designed in order to investigate the relative role of the different components of teachers' professional competence, in particular, their professional knowledge and motivation across contexts. The most remarkable result was the stable finding that teachers' utility value was a crucial component of technology-enhanced teaching across all contexts and study approaches.

In line with generic conceptualizations of utility value, the utility value of educational technologies was attributed to achieve short- and long-term goals (Canning et al., 2018; Eccles & Wigfield, 2002; Gaspard, 2015). A potential short-term goal of using technologies during teaching could be to support teaching and learning processes in a particular lesson. In addition, a potential long-term goal could be to prepare students for a digitized world. Accordingly, in the present dissertation, *utility value* encompassed the perceived added value of integrating technologies into teaching as a means to foster distinct teaching and learning processes. Furthermore, utility value was conceptualized with regard to the perceived societal relevance of using technologies in the classroom such as the perceived added value of using technologies during teaching to support students' digital literacy (based on van Braak et al., 2004). Regarding the quality of technology-enhanced lesson plans (Study 1) utility value mediated the effect of teacher expertise on the quality of technology integration. That is, teachers with higher expertise (i.e., trainee and in-service teachers) perceived higher utility value and, even more interestingly, higher utility value led to higher quality. With regard to the quality of lesson documentations investigated in Study 2, this relation was confirmed by applying growth curve models, which accounted for the individual trajectories of utility value and technology integration, as well as by conducting qualitative analyses of the lesson descriptions. In addition, Study 3 replicated these findings in a Norwegian teacher sample and showed that utility value was related also to the overall frequency of technology integration. In particular, the more strongly teachers were convinced of the added value of integrating technologies into their teaching the more often they also used technologies during teaching.

As a particular strength of the present dissertation, the diverse methodological and statistical approaches yielded the same result that utility value is crucial for technology integration. In this respect, utility value was consistently the most important factor to explain differences in the quality of technology integration independent of how the latter was assessed, that is, technology exploitation or technology-enhanced teaching quality (see Chapter 9.4.1 for more details). In particular, utility value was positively related to technology integration meaning that high utility value led to more frequent and higher quality technology integration. In line with the expectancy-value theory, teachers' value beliefs potentially led to an increased effort and persistence in using technologies during teaching (Eccles & Wigfield, 2002). In particular, it seems that if teachers perceived a high added value of integrating technology into their teaching, they were better able to implement technologies in a meaningful and efficient way (see Canning et al., 2018, for similar findings on students' effort).

In addition to the relation of teachers' motivation and their technology integration to foster teaching and learning processes, Study 3 examined the relation of teachers' motivation and their emphasis on developing students' digital literacy. In previous studies, the measure of the emphasis teachers put on developing students' digital literacy was conceptualized as a quality indicator of technology integration (e.g., Siddiq et al., 2016). Therefore, it was, at first sight, surprising that teachers' utility value was not related to the emphasis teachers put on developing students' digital literacy in Study 3. Nevertheless, this measure is very different from the measures applied in Study 1 and Study 2. First, the applied measures were derived from lesson plans and lesson documentations and were therefore not self-reports. Second, the measures focused on the innovativeness and instructional quality of the technology-enhanced teaching and not on the potential impact on students' digital literacy. Furthermore, the measures of teachers' utility value differed between the studies. Whereas in Study 1 and Study 2 utility value was assessed with regard to the societal relevance and relevance for teaching and learning processes, Study 3 only focused on the relevance of educational technologies for teaching and learning. This might have had an influence on the strength of relations between utility value and technology integration. According to Eccles and Wigfield (2002), utility value emphasizes the subjective perceived usefulness of engaging in a task for achieving individual goals. Therefore, the kind and fit of the utility value scale, outcome measure, and individual goals might be decisive to detect relations among them. This means that if a teacher perceives an added value of integrating technologies to make teaching more efficient, this value belief might only influence the use of technologies to enhance teaching processes. On the contrary, if a teacher only perceives a value of technologies to develop students' digital literacy, this value belief might only be related to teaching behavior that fosters students' digital literacy but not to the general use of technologies during teaching (see Harackiewicz & Priniski, 2018, for a review on the differential effects of diverse facets of utility value).

In addition to utility value, *self-efficacy* was investigated as a crucial component of teacher motivation. In the present dissertation, self-efficacy encompassed the confidence in implementing TET-related activities. In Study 1 and Study 2, self-efficacy was investigated in a holistic way with regard to teachers' competence in teaching with technologies. The analyses indicated that this holistic self-efficacy was not related to the quality of technology integration. Therefore, in Study 3 a more differentiated view of TET-related self-efficacy and its relation to technology integration was deployed. Following the assumption that self-efficacy constitutes an individual's judgement of his/her capabilities (Bandura, 1982; Rigotti et al., 2008), the TPACK questionnaire by Schmidt et al. (2009) was applied as a multidimensional self-efficacy measure (Scherer et al., 2017). This approach represented the proposed multidimensionality of TPACK by Mishra and Koehler (2006) by applying a bifactor(1-S)-model. This model sought to be a further development of the found nested data structure of self-efficacy by Scherer et al. (2017). Bifactor(1-S)-models consider that the different dimensions of one construct (i.e., self-efficacy) represent one general factor, but at the same time have distinct characteristics, which are captured in specific dimensions (Eid et al., 2017). Additionally, bifactor(1-S)-models encompass one reference factor to account for the single-level sampling process of the study (i.e., one measurement point), which results in an interdependence of the different dimensions of self-efficacy from a psychometric point of view. To this end, all dimensions are contrasted with the reference factor. In the case of TPACK self-efficacy, TK was chosen as a reference as it was shown to co-vary less with the other TPACK-dimensions in previous studies (e.g., Akyuz, 2018; Scherer et al., 2017). Therefore, it was possible to model the differential relations between the different dimensions of technology integration. As expected, this multidimensional representation fit the structure of the TPACK self-efficacy very well. Therefore, this approach seems to be an appropriate statistical method to deal with the mixed findings regarding the factorial structure of TPACK observed in previous investigations (e.g., Archambault & Barnett, 2010; Castéra et al., 2020; Lin et al., 2013). The analyses in Study 3 showed that self-efficacy is directly and indirectly related to the frequency of technology integration (i.e., supports the integrated mechanism model). Therefore, for the overall frequency of technology integration these direct and indirect relations between self-efficacy and technology integration should be taken into account. This is in line with findings obtained from representative large-scale studies such as ICILS 2013 and ICILS 2018 (Fraillon et al., 2019), which found positive associations between teachers' self-efficacy and the overall frequency of technology integration. Additionally, the analyses of the present dissertation indicate that the different dimensions of teachers' TPACK self-efficacy differ in their significance for technology integration. The findings showed that especially TPK self-efficacy was, compared to the other dimensions of self-efficacy (i.e., TCK, TPCK self-efficacy), relevant for the frequency of technology integration and the emphasis that teachers put on developing students' digital literacy. Technological-pedagogical knowledge (TPK) can be conceptualized as teachers' pedagogical knowledge related to the use of technology. Lachner et al. (2019) investigated the relations of TPK with other prevailing knowledge components, which were all assessed with performance-based tests. The authors showed that teachers' TPK is related to their pedagogical knowledge (PK), but surprisingly not to their technological knowledge (TK). Therefore, for TPK, pedagogical knowledge seems to be more important than its technological component. Together, these findings are in line with the present studies which showed that TPK self-efficacy might be more important for the quantity and quality of technology integration than other dimensions of TPACK self-efficacy.

In contrast, in Study 2 self-efficacy beliefs did not predict the frequency of technology integration. These contradictive findings could be due to the fact that the frequency of technology integration was measured differently in Study 2 than in Study 3: The frequency of technology integration in Study 3 was, as in ICILS 2018, assessed by an overall frequency rating (i.e., "How often did you use technologies in your class in the following classroom scenarios?"). In contrast, in Study 2 teachers indicated their technology use weekly for each past week (i.e., "This week, I used technologies in X lessons of Y lessons taught). Therefore, the measure of Study 3 provided an overall picture of teachers' technology integration, whereas the measure of Study 2 examined the frequency of technology integration in a situated manner with regard to a clearly defined time frame. In line with the differences in the frequency measurement (global vs. situated), the self-efficacy was assessed either as a global measure regarding the general confidence in the ability to teach with technologies (Study 3) or as a situated measure asking for the confidence in one's own abilities within the concrete context of the study (Study 2). In this regard, the studies add to the current debate on motivation being either relatively stable across contexts (i.e., trait-like) or context-sensitive and therefore variable across situations (i.e., state-like; Eccles & Wigfield, 2002; Reeve, 2016; Su et al., 2018). The findings of the present studies suggest that TET-related self-efficacy might be relatively stable across contexts. This tentative conclusion can be drawn from the stability of specific TET-related self-efficacy ratings across the six consecutive weeks in Study 2 as well as from the association between generic TET-related self-efficacy and the overall frequency of technology integration in Study 3. In contrast, utility value seems to be more state-like and therefore variable and dependent on contextual aspects. This conclusion can be particularly drawn from the qualitative analysis of Study 2, but also from the fact that utility value and the quality of technology-enhanced lesson plans in mathematics were related in Study 1. Additionally, the relation of utility value and overall frequency of technology integration in Study 3 suggests that TET-related utility value might also have a small facet that is trait-like and therefore is stable across different lessons. For example, one teacher might perceive an added value of integrating technologies in schools in general which might result in a robust base level of utility value and relatively high overall frequency of technology integration (i.e., trait-like facet). However, the teacher might have more differentiated value beliefs when it comes to his own teaching and he might only see the added value in using technologies for distinct teaching approaches (i.e., state-like facet). Therefore, the perceived utility value might vary across lessons and, aligned to that, the TET quality might vary. However, as the investigation of teacher motivation as state-like and/or trait-like was not the focus of the present dissertation, these conclusions should be treated with caution.

The dominating positive relation of teachers' motivation and their technology integration might also be explained by the contexts of the different studies. In each context, technologies had been newly introduced into the teachers' classrooms only recently. Even though this introduction had taken place to varying degrees, there were ongoing processes of change with regard to technology-enhanced teaching in the different contexts (in regular classrooms in Study 1 and especially within the one-to-one initiatives in Study 2 and Study 3). According to the prominent change management model by Lewin (1947), these change management processes can be differentiated into three phases (Hussain et al., 2018). The first phase, *unfreezing*, includes the planning and preparation of the change process. The second phase, *changing* or *movement,* includes the implementation of the changes, and the third phase, *refreezing,* includes the establishment of the made changes. All the teachers of the present dissertation were in the second phase and confronted with the changes accompanying the introduction of technologies such as new complexity and challenges of TET. In this phase of ongoing change, motivational beliefs are known to play an important role (e.g., Specht, Kuonath, Pachler, Weisweiler, & Frey, 2018; Wright, Christensen, & Isett, 2013). Therefore, it might be the case that the prevalent importance of teacher motivation relative to professional knowledge is an artifact of this situation. This conclusion results in two different implications. First, the relation of teacher motivation and technology integration should be further researched also in contexts that have a longer, already established tradition of TET. Second, the introduction of technologies in schools should be seen as an immense change process for the teachers that requires teachers to change their whole teaching processes and potentially rethink their deliberate practice. In line with literature on change management processes, teachers should become involved in these change processes to actively participate and eliminate potential reservations (Hussain et al., 2018). Early technology acceptance models (Davis, 1986) mainly focused on the problems of introducing new technologies into existing processes and what factors make employees accept these new technologies. For example, Holden and Karsh (2010) reviewed studies from 1999 to 2008 which investigated the relation of employees' perceived usefulness, attitude and acceptance, and use of health information technology (N = 21 studies based on 14 data sets). Notably, across all studies the perceived usefulness and intention to use or actual use of health IT was significantly related. Therefore, research on change management, technology acceptance, and research in the field of technology-enhanced teaching should be integrated. In this respect, teachers should be seen as *agents of change* when it comes to integrating technology in schools (Ertmer & Ottenbreit-Leftwich, 2010). This would potentially lead to a comprehensive understanding of the relationship between teacher motivation and technology integration. Based on this understanding, one can derive implications for educational practice and policy makers. In a first step towards this goal, the present dissertation provides a comprehensive conceptualization of both technology integration and associated professional competencies.

In sum, the studies of the present dissertation are, to my knowledge, the first studies that investigated the technology integration in this qualitative manner and systematically related it to teachers' utility value and self-efficacy. Thus, the findings provide comprehensive insight into the relationships of teacher motivation and technology integration; however, based on the present investigations, three issues remain open with respect to teacher motivation which require further research: First, the concrete mechanisms of teachers' value beliefs and self-efficacy on the quantity and quality of technology integration should be further investigated. For example, qualitative analyses of think-aloud protocols during lesson planning or retrospective interviews with teachers might provide further insights into the question of whether higher value beliefs lead to more effort or if there are other mechanisms. Second, teachers' value beliefs and self-efficacy should be examined as potential multidimensional constructs. That said, the differential relations between the different facets of teachers' utility value and their technology integration should be further investigated in future studies with a special focus on the potential influence of the fit of outcome and utility value measure. In this regard, the multidimensional representation of TPACK self-efficacy in Study 3 was a first valuable attempt. However, the found relation of the subcomponent of TPK self-efficacy and technology integration should be further analyzed and specified in future studies. Third, further research should examine the state-like and trait-like components of teacher motivation in longitudinal studies to get a more pronounced picture of TET-related teacher motivation.

9.4 Theoretical Implications

9.4.1 Comprehensive conceptualization of technology integration

The first major contribution of the present dissertation is the established comprehensive conceptualization of technology integration. This conceptualization is based on previous literature on instructional quality (Baumert & Kunter, 2006; Hamilton et al., 2016; Hugener et al., 2009; Kunter et al., 2013) and technology exploitation (Hughes et al., 2006; Puentedura, 2006) and, more importantly, on the results of the empirical studies of the present dissertation. To provide a comprehensive framework, technology integration is conceptualized as multiple pillars that constitute technology integration (see Figure 25. **Developed** conceptualization of different dimensions of technology integration.presents an overview of the different aspects of the developed and applied conceptualization of technology integration in the present dissertation.

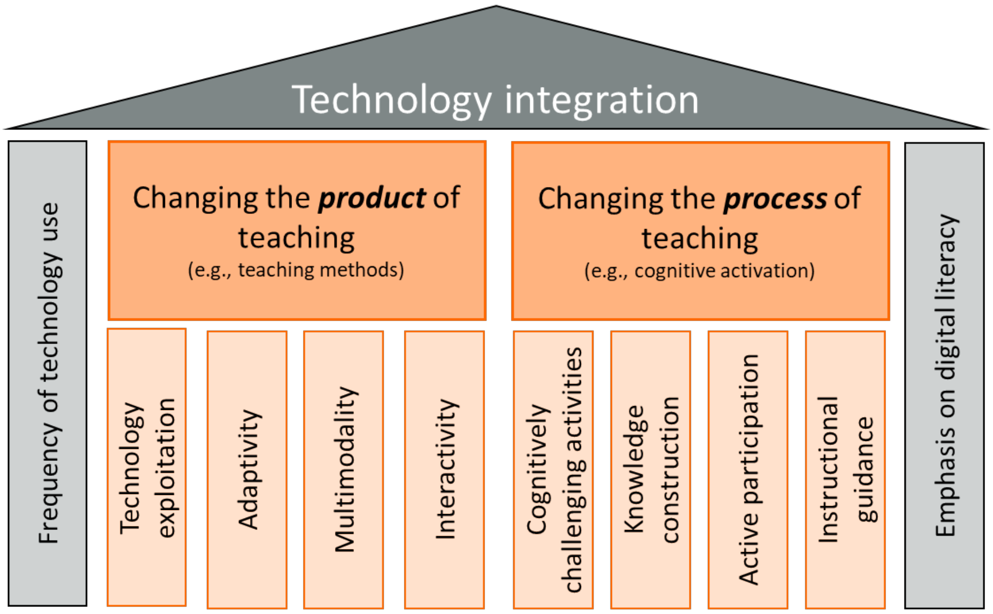

Figure 25. Developed conceptualization of different dimensions of technology integration.

Frequency of technology use and the emphasis teachers put on developing students' digital literacy are defined as the embracing pillars. Therefore, the frequency of technology integration and emphasis on digital literacy should support the core of the conceptualization and aspired goals of technology integration: changing the product of teaching, and even more important, changing the process of teaching and learning (Hamilton et al., 2016). The *product of teaching* is the sight structure of the lesson, namely what you can directly observe within the lesson such as how the lesson is organized and which teaching methods follow successively (Kunter & Voss, 2011). Therefore, the product of teaching can be changed through technology integration by applying innovative teaching methods and by using the features offered by the distinct hard- and software (Hamilton et al., 2016). According to TEL research, the most prominent features of digital tools are adaptivity (i.e., the option to adapt the difficulty of the learning material to students' needs; Ma et al., 2014; Zhu & Urhahne, 2018), multimodality (i.e., use of representations in different formats; Moreno & Mayer, 2007; Renkl & Scheiter, 2017), and interactivity (i.e., interactivity among the learners through increased communication and collaboration as well as interactivity with the learning material in self-regulated learning processes; Azevedo, Moos, Johnson, & Chauncey, 2010; Fu & Hwang, 2018; Lachner et al., 2019). The most important, but also most complex aspect of technology integration in the classroom is the *change of the teaching and learning processes* (Endberg, 2019; Hamilton et al., 2016). The change of processes of the lesson refers to the deep structure of the lesson. In particular, this includes not only the characteristics of the teaching and learning processes such as the distinct learning material used and the handling of the learning material by the learners but also the teachers' role during the teaching and learning processes (Kunter & Voss, 2011). The change of these teaching and learning processes should lead to a high quality of technology integration with powerful learning environments that support students' learning in the most appropriate way (Gerjets & Hesse, 2004; Jonassen, 2005). To elaborate on the quality of technology integration, in line with indicators for generic teaching quality, four aspects should be considered (e.g., Hugener et al., 2009): First, cognitively challenging activities and complex learning tasks such as inquiry learning scenarios in virtual experiments should be provided (De Jong et al., 2013; Kunter et al., 2013). Second, students' conceptual knowledge construction should be supported and the students should learn the relationships of different concepts (Sinatra & Pintrich, 2003). Third, the students should be encouraged to actively participate in the course of the lesson such as to explain the connections of the different concepts (Jacob et al., 2020). Fourth, in addition to the prior categories which mainly focus on the level of cognitive activation, instructional guidance should be provided such as feedback and assistance (Hardy et al., 2006).

Together, the newly developed and empirically tested categories capture the quality of technology-enhanced teaching processes. Therefore, they provide more differentiated insights into teachers' technology integration than currently applied measures (i.e., distal indicators such as the frequency of technology use) and are simultaneously less time consuming than qualitative analyses. In addition, the ratings derived from the categorizations can be used to model the relationships with other constructs such as teachers' professional knowledge and motivation. Therefore, the provided conceptualization offers new possibilities for the empirical investigation of the quality of technology integration and its boundary conditions in (controlled) experiments.

In sum, the presented conceptualization of technology integration should be regarded as a conceptual framework and tool for the analysis of teachers' technology integration. From a practical point of view, however, it is often difficult to sharply differentiate the aspects for product and process of TET. This is due to the fact that product and process of teaching are interrelated and influence each other. For example, an increased personalized adaptivity of the teaching methods is expected to yield cognitively challenging tasks for the students as each student is always challenged but not overstrained (Ma et al., 2014; see zone of proximal development, Chaiklin, 2003). Nevertheless, research such as the COACTIV study showed that the characteristics of the teaching and learning processes have a larger impact on students' learning than the product of teaching such as the teaching methods used (Kunter & Voss, 2011). The established aspects of the present conceptualization were derived from empirical research which found that these aspects are related to students' learning, however, the exact mechanisms in TET were not examined so far. Therefore, the developed conceptualization of technology integration of the present dissertation should be further examined and investigated in future studies. These investigations should also encompass analyses of in situ measures of how teachers integrate technologies such as observations of teaching in the classroom or analyses of videotaped technology-enhanced lessons. Additionally, for example, the impact of the different aspects of the conceptualization on students' learning could be investigated.

9.4.2 Framework of TET-related professional competencies

Based on generic frameworks of teachers' professional competencies (Baumert & Kunter, 2006) and the empirical findings of the present studies, I further differentiated the opportunity-to-learn model for technology-enhanced teaching by Lachner et al. (2020) described in Chapter 5.1. Lachner et al. included teachers' competencies as one conclusive boundary condition for technology integration. In this respect, one of the aims of the present dissertation was to further differentiate different aspects of teachers' professional competencies, namely their professional knowledge and motivation. To achieve this aim, the present dissertation empirically investigated the differential relations of teachers' competencies and their technology integration. Based on these empirical findings, the dissertation provides modifications of the opportunity-to-learn model for TET (Lachner et al., 2020) which encompass further differentiations of teachers' professional competencies. In particular, the motivation of teachers proved to be dominantly relevant for TET, while professional knowledge played a subordinate role. Therefore, the theoretical assumptions in the model by Lachner et al., such as the relation of teachers' competencies and their technology integration, could be empirically supported and further differentiated. The resulting model further distinguishes professional knowledge and motivational beliefs (see Figure 26). In line with the findings of the studies, utility value is highlighted as a crucial factor for technology integration. However, the relations of professional knowledge and technology integration as well as self-efficacy and technology integration are only dotted as the empirical findings indicate that these relations depend on the concrete kind of technology integration.

Embedding the empirical findings of the present dissertation into the model by Lachner et al. is important in order to acknowledge the complex structure and instructional context in which technology-enhanced teaching is implemented. In addition, especially the analyses of the teacher diaries (Study 2) showed that the instructional context determines the quality of TET. Therefore, the existing grey shaded box in Lachner et al.'s model was supplemented by *instructional context* to highlight its importance. This implies that even when a teacher has very high levels of professional competencies with a lot of knowledge and the appropriate motivation, the planned teaching methods may still not work out due to contextual circumstances. Therefore, it is important for the teachers to comprehensively understand the context in which they have to teach to be able, for example, to anticipate potential problems and obstacles (e.g., instable Wi-Fi, low-achieving students). These findings are partly in line with the recently published extension of the TPACK model by Mishra (2019). There, he postulates that the knowledge about contextual aspects in which teachers have to act should be taken into account when investigating teachers' TPACK. He, therefore, added contextual knowledge (XK) to the TPACK model. He considered as contextual knowledge every aspect that potentially influences teachers' behavior in the classroom including teachers' knowledge of available technologies at school, school-related guidelines, and nationwide policies. According to Mishra, this knowledge about the circumstances of technology integration may influence the extent and type of technology integration. In this regard, Study 2 partly supports this claim that teachers need to know the contextual aspects such as which technologies are available at their schools. However, whereas Mishra conceptualizes contextual knowledge as a rather static knowledge component, the present Study 2 indicates that teachers' knowledge of the instructional context has to be highly flexible and adaptive to current happenings in the classroom. For example, the teacher has to know how to cope with suddenly occurring problems and obstacles such as no internet connection or students' disruptions.

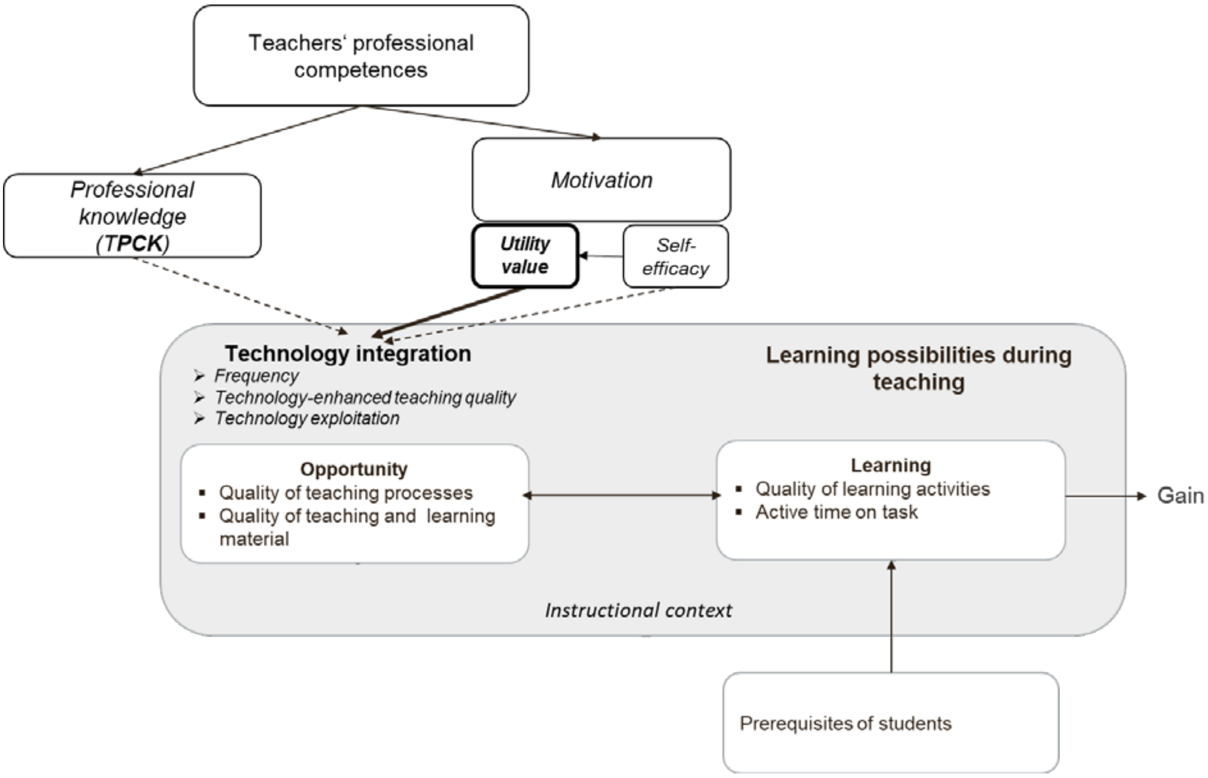

Figure 26. Adapted opportunity-to-learn model for technology-enhanced teaching based on Lachner et al. (2020)

The first aspect of professional competence for TET is *professional knowledge*. According to previous conceptualizations, teachers' professional knowledge for technology integration is composed of knowledge about technological tools (TK), domain-specific content knowledge (CK), and pedagogical knowledge (PK; Mishra & Koehler, 2006). Following the TPACK model, teachers need to integrate these basic components to be able to, for example, meaningfully combine pedagogical methods with characteristics of a certain content (PCK; Shulman, 1986), or technological tools with pedagogical methods (i.e., TPK). However, in Study 1, PCK was the only dimension of professional knowledge that was considerably related to the quality of technology integration. In line with the conceptualization and findings on the importance of PCK for generic teaching quality (Hill et al., 2008; Krauss et al., 2008; Kunter et al., 2013), the results of the present study suggest that teachers' PCK such as the knowledge about students' misconceptions enabled them to implement high technology-enhanced teaching quality to some extent. However, relative to their motivation, PCK was less important. This finding stands in contrast to the postulated model by Baumert and Kunter (2006) who postulated professional knowledge as the core variable of teachers' professional competencies. In this regard, the COACTIV study indicated that PCK was the dominant factor. In the present dissertation, the PCK was also related to the quality of technology integration, but was less important than motivational beliefs.

The second aspect of teachers' professional competencies is their *motivation* which has been found to be especially important in technology-rich classrooms (van Braak et al., 2004; Sang et al., 2010; Teo et al., 2018). All the empirical studies of the present dissertation followed the reasoning of expectancy-value theory (Eccles & Wigfield, 2002) that suggests that both teachers' self-efficacy *and* utility value concurrently affect technology integration. In particular, the studies of the present dissertation showed consistently that teachers' utility value is positively related to the quality of technology integration. In addition, in line with expectancy-value theory, self-efficacy and utility value were directly related to the overall frequency of technology integration in Study 3. Expectancy-value theory was already applied in two prior studies on technology integration: Wozney et al. (2006) showed that both teachers' self-efficacy and utility value were related to the frequency of technology integration, whereas Taimalu and Luik (2019) found relations of only teachers' self-efficacy, not their value beliefs, on the frequency of technology integration. In this regard, the present dissertation suggests that self-efficacy and utility value might have differential effects on technology integration. Whereas for the overall frequency of technology integration teachers need both utility value and self-efficacy, for the quality of technology-enhanced teaching their value beliefs might dominate. Therefore, it might depend on the kind of investigated technology integration whether a relation between teacher motivation and technology integration can be observed. Additionally, the different findings might be attributable to the different contexts in which the studies took place. Whereas Study 1 and Study 2 of the present dissertation were conducted in Germany, Study 3 was conducted in Norway, Wozney et al.'s study in Quebec, and Taimalu and Luik's study in Estonia. Therefore, the different educational systems and teacher education programs may have an impact on how teacher motivation affects technology integration. In line with this reasoning, differences in the relations of teacher motivation and technology integration between educational systems were found by Scherer and colleagues (2018). The authors investigated in a meta-analytic structural equation modeling approach the relations of teachers' motivation and their behavioral intention to use technologies in 114 studies. The analyses revealed that the relation of value beliefs and behavioral intention to use technologies was greater in non-Asian samples than in Asian samples.

Besides investigating relations based on the expectancy-value theory, mechanisms based on the technology-acceptance model (Davis, 1989) were also tested in Study 3. With that approach, the attempt was made to integrate two lines of research that are mostly separate from each other. Whereas there is a large body of research investigating the relations of individuals' motivation and their behavior (e.g., Eccles & Wigfield, 2002), this research is often neglected when it comes to investigating motivational boundary conditions for technology integration. Technology use is mainly researched based on technology acceptance models (TAM) which were established in the context of information system research (Davis, 1986; Scherer et al., 2019; Teo, 2009, 2011). From a motivational psychological perspective, it is surprising that these models focus only on attitudes and perceived utility. Self-efficacy beliefs are only considered in extended versions of the TAM and are regarded as external variables (Scherer et al., 2019). These external variables presumably influence technology integration only indirectly via the attitudes and perceived utility (i.e., cascade mechanism). Empirical investigations of the cascade mechanism showed that if self-efficacy is incorporated as an external variable into a model it explains a huge part of the variance in teachers' technology integration (Scherer & Teo, 2019). Study 3 of the present dissertation extended this view by suggesting an integrated model to describe how motivation relates to technology integration. This model encompasses both the cascade mechanism based on the TAM and the concurrent mechanism based on expectancy-value theory. With this approach, 22.5% of the variance of teachers' frequency of technology integration could be explained. This is very remarkable as the model only encompassed two components of motivational beliefs: self-efficacy and utility value. Plenty of other potentially influencing factors such as professional knowledge, infrastructure, and contextual aspects, as well as other components of motivational beliefs were not taken into account. Together, regarding teacher motivation, the empirical investigations of the present dissertation showed that both self-efficacy and utility value are related to the overall frequency of technology integration. Therefore, the studies suggest that teachers need to perceive both high self-efficacy and high utility value of educational technology in order to use technologies frequently. However, to use technologies in a high-quality manner in a specific situation, teachers might need to perceive an additional value to use technologies in that distinct teaching activity. Therefore, in Study 2, teachers' utility value was likely a dominating factor for their technology integration.

In sum, the proposed framework of TET-related professional competencies encompasses both aspects of professional knowledge and more dominantly teacher motivation. As this framework is embedded in the opportunity-to-learn model, it is evident that teachers' competencies influence the complex structure of technology-enhanced teaching and subsequently the students' learning. Within the established framework, teachers' utility value is highlighted as it was found to be a crucial enabler of their technology integration across contexts.

However, the present conceptualization of teachers' professional competencies needs further investigations with regard to four aspects. First, it might be reasonable to investigate the relation of teachers' competencies also to the quality of TET that is assessed with in-situ measures such as classroom observations. These classroom observations potentially allow analysis of TET quality within the classroom and therefore teachers' associated competencies to cope with the complex situations within the classroom. However, these findings might be confounded to a large extent with aspects of the instructional context such as available technical infrastructure, the topic taught, or the students' motivation. Therefore, from an empirical point of view, it might be a challenge to assess TET through observations as systematically as it was done in the studies of the present dissertation. The analyses of the pre-defined outline of the lesson plans and lesson documentations (i.e., given spreadsheet and prompts) in the present dissertation allowed for a very systematic assessment and analysis and therefore an efficient investigation of how the TET-related quality was related to teachers' competencies. Therefore, it might be reasonable to mix those two approaches, such as by pre-defining the topic and the grade level that teachers have to teach as was done in the study by Hugener and colleagues (2009) and additionally providing equivalent technical equipment for participating teachers. Second, it should be noted that the professional knowledge of teachers was only examined in the first study of the present dissertation. Therefore, teachers' professional knowledge for TET should be further investigated to validate and replicate the present findings. As it was the case in the current dissertation, these empirical studies should assess teachers' professional knowledge with test-based or performance-based measures. To date, mostly self-assessment questionnaires have been used to assess teachers' professional knowledge. However, these questionnaires have been recently discussed as rather depicting self-efficacy beliefs and are therefore a potentially biased proxy for the availability of knowledge (Lachner et al., 2019; Scherer et al., 2018). Furthermore, it is important to capture different aspects of professional competencies, namely professional knowledge and motivation concurrently to obtain comprehensive results. Only these comprehensive results can provide insight into the relative importance of the different aspects of professional competencies. Third, the differences of how professional competencies and technology integration are related across educational systems should be further investigated. This way, potential varying boundary conditions could be further examined which could potentially help to understand the big picture. Fourth, the differential effects of self-efficacy and utility value on technology integration should be investigated in subsequent research. This could be implemented in longitudinal research that investigates different measures of technology integration such as frequency and TET-related quality and associated motivational beliefs.

9.5 Practical Implications

The present dissertation showed that teacher motivation is a crucial determinant of technology integration across contexts. Additionally, motivation was shown to be more important than professional knowledge. The significance of teacher motivation also in the technology-rich contexts of the present empirical investigations indicates that infrastructure is an apparent and necessary condition for technology integration that enables teachers to use technologies more often. However, the availability of technologies does not seem to be sufficient for teachers to use technologies in a high-quality manner. According to the findings of the present dissertation, teachers have to perceive that educational technologies have an added value to use them in an efficient and meaningful way. This finding implicates that teacher education programs should help future teachers to experience this added value. Increasing the perceived value of educational technologies for teachers could be achieved by applying value interventions in teacher education. Utility value interventions typically highlight the added value of doing a certain task or activity for an individual's short- and long-term goals. Utility value interventions have been found to be successful approaches to increase the utility value for example of pupils in mathematics (Gaspard et al., 2017) and of college students in biology (Canning et al., 2018). For example, Canning et al. (2018) examined in a longitudinal study with STEM major students ($N = 577$) how a utility value intervention affected students' learning and study choice behavior. The utility value intervention consisted of asking the students to write one to four essays about why and how the topics learned were personally relevant for them and their individual future goals. The analyses showed that students who received a utility value intervention earned higher grades in the course, were more likely to enroll in a follow-up course, and were less likely to abandon their STEM major than students who did not receive any utility value intervention. Informed by this prior research, utility value interventions for teacher education could be developed and their effects evaluated in future studies. These utility value interventions might encompass the benefits of using educational technologies during teaching for the sake of fostering teaching and learning processes as well as increasing students' digital literacy. The increase of teachers' utility value potentially would lead to more interest and persistence in this topic.

In addition to distinct utility value interventions, teacher education programs should demonstrate the added value of technology-enhanced teaching by using the technologies during teacher training. Tondeur and colleagues (2020) recently investigated in a mixed-method study the relation of perceived teacher educators' strategies and pre-service teachers' TPACK (N = 688) and, in addition, the perception of teacher education strategies in interviews with a selection of the pre-service teachers (N = 22 interviews). The analyses showed that pre-service teachers' TPACK could be particularly improved if teacher educators were role models in using technologies during teacher education trainings. Therefore, teachers may have seen the benefits of using technology in the classroom, which may have positively influenced their TPACK.

In addition to promoting the benefit of technology use during teaching through role models, technology-enhanced teacher trainings have to demonstrate good-practice examples on how to best integrate technologies into teaching. The relatively low levels of technology exploitation in the present studies might have occurred because teachers were not aware of different possibilities on how to integrate technologies into their teaching. In particular, the qualitative analyses of Study 2 showed that teachers were more likely to be able to implement high-quality teaching if they used existing technological subject-specific tools. These tools already implied how they could be usefully integrated into the teaching of a specific subject (e.g., GeoGebra, mbook). In contrast, domain-general tools such as collaborative whiteboards, or audience response systems tended to lead to chaotic situations. Therefore, teachers might also need teacher trainings that show different possibilities on how to integrate domain-generic technologies into their teaching. Within these teacher trainings, teachers need to learn how to integrate these technologies into their subject-specific teaching. Therefore, TPK and PCK are important components of these TET-related teacher trainings. The demonstrations within the teacher trainings could be complemented by the teachers' direct testing of different applications. Therefore, for example, pre-service teachers could be encouraged to use technologies during short teaching sequences. This principle of 'approximation to practice' is often proposed within teacher education and widely applied, for example, in so-called micro teachings (Darling-Hammond, Hammerness, Grossman, Rust, & Shulman, 2005; Seidel, 2006). In these micro teachings, (pre-service) teachers are encouraged to implement newly learned teaching methods in short teaching sequences in front of other (pre-service) teachers. Thus, the complexity of teaching is reduced and at the same time (pre-service) teachers are encouraged to rehearse and develop components of the complex (technology-enhanced) teaching practice (Grossman & McDonald, 2008). However, so far, within teacher education trainings for technology-enhanced teaching, often technological knowledge is in focus and taught in an isolated manner (Tondeur, Scherer, Siddiq, & Baran, 2017).

The significance of teacher motivation when introducing technologies in schools might be especially important for policy makers. In line with change management models (Hussain et al., 2018; Lewin, 1947) and technology acceptance models (Davis, 1986; Scherer & Teo, 2019) teacher motivation might be especially relevant in the phase of changes through the technology introduction in schools. Therefore, teachers should be involved in these change processes, and teacher motivation should be considered as crucial factor and potential enabler. A further interesting aspect for policy makers is the result that teachers were more likely to deliver high-quality teaching if they could use existing tools that already combined technological features and domain-specific characteristics in a meaningful way. To a certain extent, these tools already offered an elaborate TPK solution. Therefore, as a first step, especially for teachers with little experience it would be important to provide them these ready-to-use tools for their subject-specific teaching.

Besides the content-related aspects of the present dissertation that can be implemented in teacher education, the developed teacher diary can be used to evaluate teacher education programs and also used as a tool for self-reflection. The teacher diary can be applied to track teachers' motivation as well as how they integrated technologies into their teaching. This information can also be used to gather a variety of good-practice examples of technology-enhanced lessons. These lesson documentations can be potentially provided to a broader audience. Additionally, the teacher diary is currently developed to serve as a self-reflection tool (see Wäschle et al., 2014, for similar approaches in self-regulated learning). Every time the teachers log in to their teacher diary, they receive an overview of their previous entries such as trajectories of their motivation over time. Future studies will investigate whether this feature promotes teachers' self-reflection of their motivation and how this self-reflection potentially influences teachers' technology integration practice.

9.6 Conclusions

This dissertation systematically examined, as one of the first empirical investigations of its kind, the relation of teachers' professional competence and the quality of their technology-enhanced teaching. Therefore, the dissertation provides a comprehensive conceptualization of both technology integration in the classroom as well as associated professional competencies. The empirical investigations revealed that teachers often struggle with a meaningful technology integration even when sufficient technical infrastructure is available. More importantly, teachers' motivation was found to be a crucial part for the quality of their technology-enhanced teaching. Therefore, the present dissertation informs both researchers as well as teacher educators and policy makers. First, prospective research can refer to the provided conceptualizations of technology integration and professional competencies and can further empirically examine the postulated categories and relations. Second, teacher educators and policy makers can use the provided empirical evidence to design and evaluate measures and teacher education programs. In these teacher education programs, it should be taken into account that the integration of technologies is a highly complex endeavor and cannot be done without thoughtfully preparing teachers. This preparation is potentially a complex and challenging task as it should focus not only on demonstrating the overall benefit of educational technologies but also the meaningful technological enrichment of pedagogical methods. However, this effort should be worth it as technology integration is not only a chance to improve the quality of teaching and learning processes but also for preparing students for their future in a digitalized world.

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