ICT-Based Instruction for Secondary School Students: The Interplay of Individual Learning Prerequisites, Use of Technology, and Student Involvement in Learning Processes

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Dedicated to my beloved grandparents

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ABSTRACT

Individual students vary in their cognitive and noncognitive characteristics, such as interests, academic self-concept, and prior knowledge (Snow et al., 1996a). Some of these student characteristics are treated as individual learning prerequisites, which is reflected in how students use the learning opportunities provided by instruction (Bransford et al., 2000; Helmke & Schrader, 2013). A consensus in the education field is that teaching is supposed to enhance all student learning and development. When exploring the appropriate methods to enhance student learning, the students' learning needs and prerequisites should be appropriately considered. Nevertheless, the complicated interaction between teaching and learning brings difficulties in educational research that investigates effective approaches to facilitate individual learning (Berliner, 2002). Additionally, due to practical considerations in classroom processes, it is challenging to simultaneously fulfill each student's learning needs and prerequisites. In response to the problem, making teaching adaptive has an enduring attraction in extensive research. The concept of adaptive teaching emphasizes the intent to provide sound support for student learning (Corno, 2008; Wang, 2001). In modern classrooms, information and communication technology (ICT) is assumed to have the potential to deliver appropriate learning opportunities by adaptively addressing individual learning prerequisites (Scheiter, 2017). However, a lack of access to technology in classroom practices constitutes one of the main obstacles to educational research to gain a comprehensive understanding of the role and usefulness of these new technologies in engaging students in learning processes (OECD, 2015b). Moreover, the inconsistent findings of empirical studies of technology-based learning increase the uncertainty about how to effectively use the new digital tools in education; thus, a more systematic and thorough examination of ICT-based instruction is needed.

To explore the use of technology for learning purposes, the present dissertation focused on the interplay of technology and student involvement in the classroom environment. Two overarching questions are asked: 1) what is the effect of using technology on student involvement in mathematics learning? and 2) how can the integration of technology in mathematics classrooms become more effective? Through conducting three empirical studies, the current dissertation aimed to gain insight into the current implementation of new digital tools in a real school environment.

Study 1 investigated the relationship between individual learning prerequisites and student involvement as well as the condition in which this relationship changes. Because distinctive features of technology facilitate curiosity and promote learning interest, this study

investigated whether the use of technology significantly moderated the effect of learning prerequisites on student involvement (i.e., situational interest, cognitive engagement). Study 1 used seventh-graders' data ($N = 2{,}286$) from the tabletBW research project, who either learned with tablet computers (tablet group) or not (non-tablet group) during the instructions. The results found that individual learning prerequisites, such as prior mathematics knowledge, intrinsic motivation, and math self-concept, positively predicted student involvement in learning processes. When comparing the students' involvement in the tablet and non-tablet groups, the findings indicated that the effect of intrinsic motivation on student involvement was significantly weaker for the tablet group's students who had used tablets in mathematics instruction for four months. Besides, the use of tablets also weakened the effect of math self-concept on students' cognitive engagement. However, the moderation effect did not occur in the relationship between prior mathematics knowledge and student involvement in mathematics learning.

Study 2 focused on the prolonged effect of using tablet computers on student involvement in learning processes. Additionally, it took an in-depth look at the integration of tablets during the mathematics classes. Based on the tabletBW research project, this study used longitudinal student data across three measurement points ($N = 1{,}278$). By conducting baseline latent change models, we assessed the persistent changes in student involvement and examined the influence on it of the quantity and quality of technology integration. After comparing the differences between the tablet and non-tablet groups, the results indicated that the tablet group students had a significantly slower decline in their situational interest in mathematics classes. However, this positive effect of using tablets was found only in the short-term (4 months), not in the long run (16 months). Furthermore, study 2 pointed out that significant changes in students' cognitive engagement in mathematics classes were significantly predicted by the type of tablet-related classroom activities: a transformative type of activities (e.g., to do simulation, to do programming) had an effect, but not an enhancement type of use (e.g., to do homework, to do calculations).

Study 3 aimed to identify how the integration of technology would impact student involvement by exploring the potential of technology in supporting adaptive teaching. By analyzing seventh graders ($N = 2{,}286$) in traditional and ICT-integrated instruction, again using data from the tabletBW project, study 3 investigated whether the students in the two conditions had different perceptions of adaptive teaching. This study also looked at whether the students' perception of adaptive teaching mediates the relationship between the use of tablet computers and student involvement in mathematics learning. This study found that adaptive teaching was perceived in three facets and that the students' perceptions of adaptive teaching were significantly different between the tablet and non-tablet groups. Additionally, using the refined constructs of adaptive teaching, this study examined student perceptions of different adaptive teaching facets. The results found that the students who had worked with tablet computers perceived a higher level of adaptive teaching than the non-tablet class students. Moreover, this study also confirmed that the mediation effect of students perceived adaptive teaching on the relationship between using tablet computers and two constructs of student involvement in mathematics learning (i.e., situational interest and cognitive engagement).

In conclusion, this dissertation provides empirical evidence for the integration of technology in real classrooms and reveals the potentials of technology in support adaptive teaching. Through unfolding the learning processes in ICT-based mathematics instruction, the findings highlight the positive influences of using technology on students' motivational and cognitive engagement in mathematics learning. Furthermore, the present dissertation gives an insight into using technology to provide appropriate learning opportunities and enhance students' active involvement in learning processes. More theoretical implications for learning theories and classroom practices and some recommendations for future research are also derived.

ZUSAMMENFASSUNG

Schülerinnen und Schüler unterscheiden sich in ihren kognitiven und nicht-kognitiven Merkmalen wie beispielsweise ihren Interessen, akademischem Selbstkonzept und Vorwissen (Snow et al., 1996b). Einige dieser Merkmale werden als individuelle Lernvoraussetzungen angesehen, was sich wiederum in der Art und Weise widerspiegelt, wie die Schülerinnen und Schüler die durch den Unterricht gebotenen Lernmöglichkeiten nutzen (Bransford et al., 2000; Helmke & Schrader, 2013). Im Bildungsbereich besteht Konsens darüber, dass Unterricht das Lernen und die Entwicklung aller Schülerinnen und Schüler fördern soll. Bei der Untersuchung geeigneter Methoden zur Förderung des Lernens müssen die Lernbedürfnisse und -voraussetzungen der Schülerinnen und Schüler angemessen berücksichtigt werden. Nichtsdestotrotz bringt die komplizierte Interaktion zwischen Lehren und Lernen Schwierigkeiten für die Bildungsforschung mit sich, effektive Ansätze zur Förderung des individuellen Lernens zu untersuchen (Berliner, 2002). Darüber hinaus ist es aufgrund praktischer Umstände in Unterrichtsprozessen schwierig, die Lernbedürfnisse und -voraussetzungen aller Schülerinnen und Schüler gleichzeitig zu berücksichtigen. Aufgrund dieser Probleme steht die adaptive Gestaltung des Unterrichts im Fokus umfassender Forschung, und das Konzept des adaptiven Unterrichts betont die Absicht, den Lernprozessen von Schülerinnen und Schülern eine solide Unterstützung zu bieten (Corno, 2008; Wang, 2001). In modernen Klassenzimmern geht man davon aus, dass Informations- und Kommunikationstechnologie (IKT) das Potenzial hat, durch die adaptive Berücksichtigung individueller Lernvoraussetzungen geeignete Lerngelegenheiten zu ermöglichen (Scheiter, 2017). Der mangelnde Zugang zu Technologien in der Unterrichtspraxis stellt jedoch eines der Haupthindernisse für die Bildungsforschung dar, um ein umfassendes Verständnis der Rolle und des Nutzens dieser neuen Technologien für das Involvement der Schülerinnen und Schüler in Lernprozesse zu erlangen (OECD, 2015b). Darüber hinaus erhöhen die widersprüchlichen Ergebnisse empirischer Studien zum technologiegestützten Lernen die Unsicherheit darüber, wie die neuen digitalen Werkzeuge in der Bildung effektiv eingesetzt werden können. Daher ist eine systematischere und gründlichere Untersuchung des IKT-basierten Unterrichts erforderlich.

Um den Einsatz von Technologie zu Lernzwecken zu untersuchen, konzentrierte sich die vorliegende Dissertation auf das Zusammenspiel von Technologie und das Involvement von Schülerinnen und Schüler in der Unterrichtsumgebung. Es werden zwei übergreifende Fragen gestellt: 1) Welchen Einfluss hat er Einsatz von Technologie auf die Beteiligung der

Schülerinnen und Schüler an mathematischen Lernprozessen? und 2) wie kann die Integration von Technologie in den Mathematikunterricht effektiver gestaltet werden? Ziel der vorliegenden Dissertation war es, in drei empirischen Studien einen Einblick in die aktuelle Implementierung neuer digitaler Werkzeuge in einer realen Schulumgebung zu gewinnen.

Studie 1 untersuchte die Beziehung zwischen individuellen Lernvoraussetzungen und dem Involvement von Schülerinnen und Schülern sowie die Bedingungen, unter denen sich diese Beziehung verändert. Da technologische Besonderheiten Neugierde und Lerninteresse fördern, wurde in dieser Studie untersucht, ob der Einsatz von Technologie den Einfluss der Lernvoraussetzungen auf das Involvement der Schülerinnen und Schüler (d.h. situatives Interesse und kognitives Engagement) signifikant moderiert. In Studie 1 wurden Daten von Siebtklässlern (N = 2.286) aus dem tabletBW Forschungsprojekt verwendet, in welchem zufällig entschieden wurde, welche Klassen mit Tablet-Computern arbeiten (Tablet-Gruppe) und welche nicht (Kontrollgruppe). Die Ergebnisse zeigten, dass individuelle Lernvoraussetzungen wie Mathematikvorkenntnisse, intrinsische Motivation und mathematisches Selbstkonzept das Involvement der Schülerinnen und Schüler in Lernprozesse positiv vorhersagten. Beim Vergleich der Schülerinnern und Schüler in Kontroll- und Tablet-Gruppe zeigten die Ergebnisse, dass der Einfluss der intrinsischen Motivation auf das Involvement bei den Schülerinnen und Schülern der Tablet-Gruppe, die vier Monate lang Tablets im Mathematikunterricht verwendet hatten, signifikant schwächer war. Zudem schwächte die Verwendung von Tablets den Einfluss des mathematischen Selbstkonzepts auf das kognitive Engagement der Schülerinnen und Schüler. Der Moderationseffekt trat jedoch nicht in der Beziehung zwischen Mathematikvorkenntnissen und dem Involvement der Schülerinnen und Schüler im Mathematikunterricht auf.

Studie 2 konzentrierte sich auf den anhaltenden Einfluss der Verwendung von Tablet-Computern auf das Involvement der Schülerinnen und Schüler in Lernprozesse. Zusätzlich wurde der Mechanismus der Integration von Tablets in den Mathematikunterricht eingehend untersucht. Basierend auf dem tabletBW Forschungsprojekt verwendete diese Studie Längsschnittdaten der Schülerinnen und Schüler über drei Messpunkte hinweg (N = 1.278). Unter Verwendung von Baseline Latent Change Modellen bewerteten wir nicht nur die anhaltenden Veränderungen des Involvements der Schülerinnen und Schüler, sondern untersuchten auch den Einfluss der Quantität und Qualität der Technologieintegration auf diese. Nach dem Vergleich der Veränderungen zwischen Kontroll- und Tablet-Gruppe zeigten die Ergebnisse, dass die Schülerinnen und Schüler in der Tablet-Gruppe einen signifikant langsameren Rückgang ihres situativen Interesses am Mathematikunterricht aufwiesen. Dieser positive Einfluss der Tablet-Nutzung konnte jedoch nur kurzfristig (4 Monate) und nicht langfristig (16 Monate) festgestellt werden. Zusätzlich deutete Studie 2 darauf hin, dass signifikante Veränderungen des kognitiven Engagements der Schülerinnen und Schüler im Mathematikunterricht signifikant durch die Art der Tablet-bezogenen Unterrichtsaktivitäten vorhergesagt wurden: transformative Aktivitäten (z.B. Durchführen von Simulationen, Programmieren) zeigten einen Effekt, nicht aber eine verstärkende Art der Verwendung (z.B. Hausaufgaben machen, Berechnungen durchführen).

Studie 3 zielte darauf ab, zu ermitteln, wie sich die Integration von Technologie auf das Involvement der Schülerinnen und Schüler auswirken würde, indem das Potenzial der Technologie zur Unterstützung eines adaptiven Unterrichts untersucht wurde. Anhand von Siebtklässlern (N = 2.286) im traditionellen und im IKT-integrierten Unterricht, erneut unter Verwendung von Daten aus dem tabletBW Forschungsprojekt, untersuchte Studie 3, ob die Schülerinnen und Schüler in den beiden Bedingungen unterschiedliche Wahrnehmungen von adaptivem Unterricht hatten. Diese Studie untersuchte zudem, ob die Wahrnehmung des adaptiven Unterrichts durch die Schülerinnen und Schüler die Beziehung zwischen der Verwendung von Tablet-Computern und des Involvements der Schülerinnen und Schüler im Mathematikunterricht vermittelt. Diese Studie fand heraus, dass adaptiver Unterricht in drei Facetten wahrgenommen wurde und dass die Wahrnehmung des adaptiven Unterrichts durch die Schülerinnen und Schüler zwischen der Kontroll- und der Tablet-Gruppe signifikant unterschiedlich war. Zusätzlich untersuchte diese Studie mit Hilfe des verfeinerten Konstrukts des adaptiven Unterrichts die Wahrnehmung der Schülerinnen und Schüler in verschiedenen Facetten des adaptiven Unterrichts. Die Ergebnisse zeigten, dass die Schülerinnen und Schüler, die im vorangegangenen Schulhalbjahr mit Tablet-Computern gearbeitet hatten, ein höheres Niveau des adaptiven Unterrichts wahrnahmen als Schülerinnen und Schüler in der Kontrollgruppe. Darüber hinaus bestätigte diese Studie den Mediationseffekt des von den Schülerinnen und Schülern wahrgenommenen adaptiven Unterrichts auf die Beziehung zwischen der Verwendung von Tablet-Computern und zwei Konstrukten des Involvements der Schülerinnen und Schüler am Mathematiklernen (d.h. situatives Interesse und kognitives Engagement).

Zusammenfassend zeigt diese Dissertation empirische Belege für eine effektive Integration von Technologie in den Unterricht und zeigt die Potenziale der Technologie zur Unterstützung eines adaptiven Unterrichts auf. Durch die Untersuchung der Lernprozesse im IKT-gestützten Mathematikunterricht verdeutlichen die Ergebnisse die positiven Einflüsse des Technologieeinsatzes auf das motivierende und kognitive Engagement der Schülerinnen und

Schüler im Mathematikunterricht. Darüber hinaus gibt die vorliegende Dissertation einen Einblick in den Einsatz von Technologie, um geeignete Möglichkeiten zu schaffen und die aktive Beteiligung der Schülerinnen und Schüler an Lernprozessen zu fördern. Darüber hinaus werden weitere theoretische Implikationen für Lerntheorien und Unterrichtspraktiken sowie einige Empfehlungen für die zukünftige Forschung abgeleitet.

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Introduction

Chapter 1 Introduction

"Tell me, and I forget; teach me, and I remember; involve me, and I learn."
—Benjamin Franklin

Education is broadly accepted as the combination of teaching and learning processes that lead to behavioral and cognitive development in learners (Martinez, 2014; Schunk, 2012). In this sense, education is expected to make a change. A consensus in school education is that teaching is supposed to support students in learning and consequently prepare individuals for society. At the same time, teachers and educational researchers are primarily interested in bringing about change in support of student learning. But how can they support and enhance learning in school settings? This dissertation begins with an age-old question in education. Learning here is not limited to changes in learners' behaviors and academic performances but also includes ongoing processes. In schools, effective learning is pursued with different teaching strategies, methods, and other factors. Frequently, the search for effective ways to enhance learning begins with the learners themselves and their interactions with the external environment. Educators and educational psychologists pay attention to any particular conditions that enhance learners' desired changes (Bransford & Council, 2000; Mishra et al., 2016a). The development of society, on the one hand, seems to complicate the conditions in education. On the other hand, opportunities and changes usually come after challenges. A representative feature of modern education is the integration of new technology in classroom settings.

Although the technology-integrated classroom is distinguished from the traditional classroom, the initial question about enhancing learning is still as crucial as ever in education. Educational researchers are concerned with how to support learning in classroom environments integrated with educational technology. On the one hand, since teaching and learning occur in a new environment, it is reasonable to expect changes in teachers' and students' roles. On the other hand, the issues that appear in new classroom settings seem more complicated than those in original settings (Shapiro & Niederhauser, 2004). In response to the changes, when rethinking the interaction between teaching and learning, researchers focus on involving individual learners in the learning processes in the technological context. One alternative way to deepen the understanding of a learner is to unfold it in a particular condition. This chapter raises issues related to learning with technology and discusses why technology-enhanced learning is more important at present. Subsequently, this chapter provides a brief overview of the availability of technology for educational purposes and digitalization processes in schools. Based on the current situation of technology-enhanced learning, the next task is to identify the gaps in this research field and explicitly outline the objectives of this dissertation. The last section provides an overview of each chapter.

1.1 Problem Statement

The central goal of education has been to promote learning. In school teaching, this objective frequently leads to a focus on student learning outcomes, such as enhancing academic achievement (Littlewood, 2007). However, students with high academic achievements may not be actively involved in or experience joy during learning processes. Active learning and involvement are essential in educational science, especially in mathematics education. For instance, cross-cultural researchers—from the third Trends in International Mathematics and Science Study (TIMSS) of 2003—tested the performances of eighth-grade students and reported that those from East Asian countries (e.g., Singapore, South Korea, Hong Kong SAR, and Japan) had achieved above-average mathematics scores over the past two decades (Mullis et al., 2016; Mullis et al., 1999). These high academic performances in mathematics are treated as indicators of effective learning. Some researchers, however, pointed out a mismatch between student engagement and achievement in the East Asian region (Song, 2013). In particular, interest and motivation regarding mathematics were treated as positive predictors of school achievement (Heinze et al., 2005; Köller et al., 2001). However, successful academic performance does not imply active involvement in learning processes (Pinxten et al., 2014). In particular, holding the interest and motivation of learners is a challenge in mathematics education (Frenzel et al., 2010). Only examining learning outcomes does not provide insights into what contributes to active learning. Based on this idea, an in-depth examination of the complicated and ongoing learning processes is vital.

To explore student involvement in the learning process, educators and researchers take a step back from the learning outcomes and pay more attention to learning activities. If learning is understood as a process, it requires active involvement; if learning is treated as an activity, it needs active participants. However, compared to observable learning outcomes, not much is known about learning processes and whether individuals are actively involved in learning. In classrooms, it is vital to involve students in cognitive and noncognitive aspects (Fredricks et al., 2004); however, many cognitive and noncognitive constructs cannot be directly observed or measured. From a theoretical perspective, it is necessary to deepen the understanding of unobservable components conducive to learning and develop a comprehensive model to explain student learning processes. Therefore, student involvement remains a work in progress for classroom practice and research (Astin, 1999; Klein, 2007). To gain more insights into the active involvement and engagement of learners in schools, educational researchers have emphasized various teaching approaches and tried different techniques.

Considering the challenges associated with conventional teaching processes, educators quickly adopt new techniques or teaching methods to fulfill individual needs (Perkins, 1991). As a result, the appropriate combination of technology and education is a much-debated topic. (Maloy et al., 2017; Mishra et al., 2009). In this situation, using educational technology to deal with students' diversity is an optimal alternative (Mishra et al., 2016b). In the 21st century classroom, educational researchers assume that high-quality teaching can effectively integrate technology in instructions (Reiser & Dempsey, 2012).

The advances of technology have rapidly changed human societies, and the field of education is no exception (Fishman & Dede, 2016). With advanced technology available for educational purposes, scholars have started to evaluate the necessity of integrating technology in learning environments (Reigeluth, 1989). More directly, educators are confronted with the question of whether to begin to use technology for teaching. This uncertain and skeptical attitude is perhaps due to a lack of understanding of whether teaching with technology makes a difference in student learning, either positively (Cheung & Slavin, 2013) or negatively (Clark, 1983; Clark, 1994). For decades, educational researchers have been concerned with how students learn and how to enhance their learning. Even in a technology-based context, promoting student learning is still the central focus of such research (Bruce & Levin, 1997; Fu, 2013).

When learning occurs in a new learning environment, deeper understandings of the student learning processes are required. In the meantime, it is a long way for researchers to find the effective approach for appropriate learning opportunities and promote student involvement in learning (Astin, 1996; Greeno & Gresalfi, 2008), especially in mathematics education (Bell & Pape, 2012; Goos, 2014; Watson, 2003). More importantly, another critical issue is that using technology for learning is a matter of equity in education (Kent & McNergney, 1999; Maloy et al., 2017). Educators, researchers, and policymakers have made extensive efforts to improve equal opportunity in education. In school settings, education equity does not mean providing identical inputs to each student. Instead, fairness is providing adequate support to each student (Anderson, 2007). To achieve equity, schooling is supposed to improve individual students with diverse learning characteristics and experiences (Broudy, 2016). Therefore, teaching has a long history of accommodating individual differences in learning, such as students' motivational and cognitive characteristics (Wang, 2001). However, obstacles prevent the fulfillment of the standard of fair learning opportunity. Considering the limited class time, teaching resources, and other practical reasons, it is difficult to achieve equity in student learning using the traditional approach (Lazenby, 2016).

Regarding the use of technology in school settings, there is no consensus on the efficacy of technology-based instruction on the student learning process (Clark, 1994), despite substantial debates on whether the effectiveness of technology on student learning is overestimated (Chu, 2014; Heinecke et al., 2001; Witte & Rogge, 2014). The contradictory arguments result from a limited understanding of how technology is used as a learning tool in the classroom. Additionally, evidence that learning with technology is beneficial remains insufficient. Even though it is extraordinarily challenging to assess the impact of technology on student learning, educational researchers can bring learning theory, use of technology, and educational practices together.

Changes in teaching approach and development in individual learning bring new schooling issues on a daily basis (Russell et al., 2005). Using technology to facilitate student learning is a complex process that lacks theoretical and practical guidance on effective implementation (Reiser & Dempsey, 2012). Both in traditional classrooms or a classroom integrated with technology, supporting student learning is an essential goal. However, new technologies may stimulate novel interactions between teaching and learning processes. Therefore, the current dissertation seeks a clearer understanding of enhancing student involvement in a technology-based classroom. To achieve this goal, more in-depth understandings at both the theoretical level and practical level are needed. Specifically, this dissertation attempts to (a) bridge learning theories with technology-based instruction and (b) seek empirical evidence of whether and how technology-based instruction influences student learning in the classroom environment. By conducting empirical studies, I make a small movement from learning theories to new classroom environments. While investigating the interaction of technology, teaching, and learning in this new environment, it is difficult to achieve the above two goals without making basic assumptions about how students learn. For instance, is learning a simple replication of knowledge, or is it an active process that requires learners' involvement? Which factors influence learning? The next section explicitly describes assumptions regarding the learning process and learners to provide a foundation for the learning theories in the present dissertation.

1.2 Constructivist Perspective of Learning

"We need pupils who are active, who learn early to find out new things by themselves, partly by their spontaneous activity and partly through materials we set up for them."

—Jean Piaget

Over the past decades, contemporary researchers have explained learning from psychological and educational perspectives (Bednar et al., 1992; Hilgard & Bower, 1966; Schunk, 2012). During this process, learning theories have adopted the fundamental perspectives of behaviorism (Skinner, 1976), cognitivism (Shuell, 1986), and constructivism (Harel & Papert, 1991). Each of these dominant perspectives explains learning processes and the nature of learning from different points of view (Ertmer & Newby, 1993; Nagowah & Nagowah, 2009). With increased attention to individual learning, researchers clarify that student learning is more than simple changes in behavior (Domjan, 2014; Lachman, 1997). From the constructivists' perspectives, learning is a complicated process that can better explain the complexity of modern education (Kintsch, 2009). Therefore, the paradigm used to explain teaching and learning has shifted from behaviorism to constructivism (Cooper, 1993). Constructivism argues that humans actively form new connections within existing knowledge and construct new understandings (Clark, 1985). The present dissertation adopts the constructivists' critical assumptions about learning.

Early constructivists argued that individuals are active learners who construct new understandings and ideas based on their prior knowledge and past experiences (Piaget, 1980; Von Glasersfeld, 2002). Rather than merely accumulating the facts, people actively recall their prior knowledge and past experiences to contribute to future learning. Specifically, during the pursuit of knowledge, people are mentally stimulated, which ultimately encourages meaningful learning (Bransford & Council, 2000). When people are actively engaged, they tend to think more deeply and are more capable of reflecting on the meanings of what they have learned. Constructivism has further developed to explain how students learn in different contexts, which have broader education implications. By bridging education and psychology, constructivism provides valuable principles for teachers and researchers to interpret their observations.

The second central argument of constructivists is that learning is an active process of acquiring knowledge and understanding new ideas (Lachman, 1997). They stress that learners spontaneously acquire knowledge and develop their competence through engagement. In other words, learning is not a passive process that merely replicates and reproduces knowledge.

Meaningful learning occurs when the learner makes efforts to interpret and make sense of the new information (i.e., input), which is later aggregated into existing knowledge (Fiorella & Mayer, 2015). In this sense, the existing knowledge and cognitive characteristics of a learner are particularly important. During this incremental process, the learner selects and transforms the relevant information into an appropriate format that contributes to the current understanding (Bruner, 1963a). The more reliably a learner connects new information with the relevant known concepts, the more knowledge they can acquire. Based on this understanding of learning, teaching is supposed to help students make appropriate modifications to their existing knowledge frameworks. When education adapts to learners' characteristics and needs as necessary, it supports student learning (Corno, 2008; Wang, 2001).

Additionally, from the constructivist perspective, learning is not result-oriented, and learners' experiences also play a critical role in the process (Wittrock, 1974). In discussing when learning takes place, educational researchers generally focus on the process more than the outcomes. Recent researchers have pointed out that the more opportunities the students gain from the instruction, the more likely they learn well (Simonsen et al., 2008). The topic of student learning also raises concerns about individual characteristics. Student characteristics vary in motivational and cognitive aspects. These characteristics are considered crucial starting points for students and are treated as prerequisites to further learning.

From the constructivist perspective, students have different characteristics in learning that are considered by teachers. As such, the relationship between teaching and learning has become a critical topic in educational research. For instance, the process-product model emphasizes the effect of teaching on learning outcomes (Brophy & Good, 1984). Early theories and models stress the challenges of delivering knowledge to students without opening the black box of student learning processes. Some later researchers focused on the effect of teaching methods on learning processes, such as providing appropriate opportunities for students to enhance their learning (Lipowsky et al., 2009). But they did not assume that learning involves complex phenomena that cannot merely be explained by intrapersonal factors or that instructional and contextual factors also influence the process. A more comprehensive model to explain the interaction between teaching and learning processes is required by acknowledging different learning theories.

In the past decades, constructivist theories have significantly influenced ideas about the interaction between teaching and learning. Educational researchers currently pursue deeper understandings of learning processes and associated factors. Although the explanations of causes, processes, and consequences of learning vary across learning theories and models, recent developments show a consensus that learning involves a complicated interaction among personal, instructional, and contextual factors. To this end, some educational researchers integrated the structured paradigm with the process paradigm and introduced a multilevel supply-use model (Brühwiler & Blatchford, 2011; Helmke & Schrader, 2013; Seidel, 2014a). This theoretical framework provides a comprehensive overview of student learning. It explains the influential factors from three broad levels: (a) supply level, (b) use level, and (c) learning outcomes level.

At the first level, the framework primarily focuses on the offer of learning opportunities. In general, this supply level includes teachers' professional competencies, teaching processes, and the external environment for learning. Teaching and instruction are viewed as ongoing supply processes that provide students the opportunity to learn. Different instructional characteristics, such as teaching methods, strategies, and technologies, provide varied learning opportunities to students (Corno, 2008). At the second level, the model mainly involves student factors and includes how students perceive and use learning opportunities. The role of each student is considered essential. According to this framework, learning in schools involves a set of interactions between teachers and students. For instance, after a teacher asks a question to test the students' initiative, they expect the student to answer. Then, the student's answer affects the teacher's evaluation of feedback or provide elaboration. In this situation, a reciprocal relationship (e.g., teacher-student reflection circle; McGlinn, 2003) is established. In many cases, if teachers and researchers attempt to enhance student learning, it is particularly important to better understand how the learning process takes place.

The idea of achieving an equilibrium between supply and demand in economics is also applicable to education. Only when the teaching process prepares the learners—neither too much nor too little—can it lead to effective learning (Wang, 2001). Thus, teaching should be adaptive, and it should meet students' diverse learning needs over a prolonged period. In this sense, if teaching and instruction are flexible and open to change, they create an ideal situation for individuals to learn. The traditional "one-size-fits-all" instruction may not be suitable for learning nowadays (Gregory & Chapman, 2012). Therefore, it is valuable to know how to match the supply and use of learning opportunities. Educators and researchers pursue alternative methods in classroom implementation to effectively accommodate teaching to students' prior knowledge and learning characteristics. During the research, it brings a few new questions: what are alternative approaches to supporting learning? How do we make them work? In response to these concerns, constructivism and the supply-use model provide a rationale for integrating technology in education (Duffy & Jonassen, 1991; Perkins, 1991; Strommen &

Lincoln, 1992). The availability of new technology makes the constructivist theories actualized in real classrooms (McGuire, 1996). Merging the use of technology with constructivist theories provides a better understanding of how knowledge acquisition takes place and possible to enhance in new learning environments (Gabbard, 2000).

In short, the previous discussion follows from the basic assumptions that student learning is an active process, and it is important to involve all students, especially those with diverse characteristics, in the learning processes. A new perspective on the interaction between learning and instruction needs to be considered to facilitate active student learning and involvement. The main priorities are to examine learning in a technology-based context and identify how students learn with technology in the classrooms.

1.3 Learning with Technology in the Classroom

In a traditional classroom, a typical scene is a teacher standing in front of the blackboard, providing information and delivering knowledge to a class of students who sit still in their seats. All students study the same topics at the same time. Most of them may be busy taking notes and trying to understand the lecture. After the teacher raises a question, there is either response from a few students or just stillness. Everything keeps moving forward, and education is also not without its changes: what learners experience nowadays in the classrooms is very different from what they experienced decades ago.

In the new era, technology is growing and integrated into schools (Cuban, 1988). Digital devices are a part of daily teaching and learning (OECD, 2015b). The term information and communication technology (ICT) is more frequently used in education today and is linked with instruction (i.e., ICT-based instruction). In education, ICT-based instruction refers to using technology and digital tools to support teaching and enhance student learning. This is the term that will be used in the present dissertation. The development of technology has rapidly changed the resources and focus on education. The annual report of the International Telecommunication Union (ITU) highlighted the advanced implementation of technology in education in countries such as Iceland, South Korea, and Denmark (ITU, 2017, 2019). However, the introduction and implementation of technology depend highly on adequate digital equipment and universal access to technology (Fraillon et al., 2018). It brings to light that the development of technology-enhanced learning differs greatly across countries. Additionally, the International Association for the Evaluation of Educational Achievement (IEA) reported that German schools lacked adequate digital equipment and that the German schools' universal access to educational technology was behind the international average (Fraillon et al., 2018). This situation is expected to change when more efforts and resources are invested in digitalizing schools. For instance, the idea of digital education has gained more prominence in Germany recently, which means German schools will have the opportunity to be better equipped with the latest digital media for teaching and learning (Hauf et al., 2019; Heinen & Kerres, 2017). Under supportive policies, the technological environments of public schools are expected to improve over time. Although there is still a long way to go for schools to fully embrace digital transformation, digitalization in the field of education has started.

Once digital devices are available, the next concern is about the context to integrate these devices in. Depending on the particular educational context, integrating the same tool can affect learning differently. Hence, the original features of specific educational contexts (e.g., higher education, primary education, etc.) must be considered. Across the long-period formative education, secondary education is vital for individual development as an indispensable link between primary education and higher education. Examining the characteristics of secondary education elucidates the integration of technology in classroom environments. In Germany, a unique secondary school system separates pupils at the end of primary school. More specifically, at the beginning of the fifth grade, pupils in public schools face a refined separation (KMBW, 2018). The core academic subjects include German as a language, mathematics, foreign languages, natural sciences (e.g., biology, chemistry, or physics), and mandatory courses (e.g., computer science, visual arts, or sports). In seventh grade, the students' competence to acquire by the end of the academic year is explicitly provided for each school subject (MKJS, 2019). Besides the general features shared at the school level, secondary school students from the same class also experience similar factors, such as class composition and learning environment. Following the curriculum requirements, if teachers prepare their lectures based on the class unit, students from the same class have to experience a similar teaching style, lesson plan, learning time, and contents of knowledge in the classroom. In other words, the students experience the one-size-fits-all curriculum. This traditional teaching approach was criticized by early educational researchers who emphasized the importance to meet individual students' needs (Murray et al., 2004). In this sense, bringing new teaching methods and techniques into classrooms is needed so that to allow students to learn in their pace.

In recent decades, educators and researchers are primarily concerned with technology for educational purposes (Sandholtz, 1997). In education, technology is a tool to assist teaching and support student learning (Lai, 2008; Stürmer & Lachner, 2018). In particular, ICT-based instruction in upper secondary education increases (Petko et al., 2017; Zhai et al., 2016). When the technology first became available, schools and teachers paid close attention to its impact on teaching and learning (Lei & Zhao, 2007). If using a new technique or approach does not lead to positive outcomes, it hinders the teacher's motivation and enthusiasm for its implementation (Hennessy et al., 2005). Therefore, educational scholars are keen to identify the appropriate level of integration of technology in education and deepen their understanding of its influence on teaching-learning processes (Bebell et al., 2004). They focus on using technology on secondary students' learning and exploring complicated interactions during integration. However, the nature of student learning is complicated. In a sense, modern education is just a new form of traditional education. The unresolved issues of conventional teaching extend to ICT-based instruction (Lepper, 1985). The problems of low interest, lack of involvement, and ineffective learning may still occur in the new environment. In addition, the interaction between teaching and learning is likely to have more varieties when technology is added. At both theoretical and practice levels, substantial factors still limit knowledge about this new type of education. After discussing the influential theories of student learning and the current context of technology-based education, it is necessary to identify the unanswered issues in this field. Thus, the following section discusses gaps in the research related to the present study.

1.4 Identifying the Research Gaps

When discussing the critical factors that influence student learning, existing learning theories and theoretical frameworks emphasize teacher factors and environmental factors. In modern education, the recent development and growth of educational technologies provide devices and software for teaching and learning. At the same time, a general trend of technological integration has begun in secondary education. On the one hand, the appearance of educational technology provides more possibilities for teaching and learning. On the other hand, educators and researchers have limited knowledge about this new technique and its effects on student learning. However, not many theories and models articulate the use of technology as a critical component of instruction or explain its impact in supporting learning processes.

Additionally, to enhance student learning, instruction should be continually aligned with students' diverse backgrounds and characteristics, such as interests, self-concepts, and cognitive abilities (Brophy et al., 2001; Wang, 2001). Some researchers suggest integrating technology to provide each student with an equal opportunity to actively engage with classroom learning. However, the introduction of technology in the German education system remains at an early stage. Consequently, technological implementation in the German education system is slightly lagging behind expectations and desires (OECD, 2015b). Without a broad integration of technology, little empirical evidence shows on how technology is integrated into a real classroom setting. Furthermore, appropriate teaching content and methods lead to positive teaching and learning (Seidel & Shavelson, 2007). However, a lack of comprehensive understanding of adaptive teaching (e.g., conceptualization, features, related classroom activities) limits the accommodation of individual differences in learning. Based on this assumption, it is crucial to discover the mechanism of technology integration. Nevertheless, whether the specific potential of technology can be used to support student learning and adaptive teaching methods remains unknown.

In classroom processes, integrating technologies not only depends on the cooperation among teachers, students, and parents but also requires equipment and organizational support. However, little study has revealed the potential for technology to improve adaptive teaching processes and student learning. Moreover, different learning conditions (e.g., working in traditional versus ICT-based classrooms) have not been considered in examining whether technology can support learning processes in the classroom. Therefore, little empirical evidence discusses the proper utilization of technology for improving student learning in classrooms.

1.5 Objectives of the Dissertation

Advanced technologies in teaching and learning appear to provide changes and open up possibilities in education. However, the rapid development of educational technology and the lack of knowledge on effective implementation widen the research gap in this field. In this dissertation, a primary assumption about technology-based instruction is that when technology is used effectively as a tool to support teaching, it has the distinctive potential to enhance student learning and contribute to equality in education. Based on this assumption, the present dissertation contributes knowledge about using technology by bridging learning theories and technology-based instruction. It closely examines how technology integration interacts with individual learning prerequisites, supports adaptive teaching, and facilitates active student learning processes. Previous literature findings are insufficient to convince teachers and educational researchers that technology can support teaching and learning in school settings. Consequently, two overarching research questions guide this dissertation.

1. What are the effects of technology-based instruction on student involvement in learning processes?
2. How can the integration of technology in mathematics classrooms become more effective?

Student learning is a dynamic and complicated process that involves many interrelated factors at the class level and individual level. Previous studies have provided various explanations for these crucial factors. To add to the field, the current dissertation consists of three empirical studies that investigate *when* (i.e., in which condition) the effect of individual learning prerequisites on student involvement in mathematics learning would change (e.g., smaller). Answering this question contributes to a better understanding of the role of technology-based instruction for student learning processes. Furthermore, in addition to the examination of the effects of using technology in student involvement in learning, the *mechanism* behind the integration, and *how* technology-based instruction enhances active learning are also identified through empirical investigations. This dissertation attempts to gain considerable insights into technology-based learning with the above theoretical and empirical work as it unfolds in a real classroom environment.

1.6 Overview of Chapters

To structure the dissertation, I divided it into seven chapters under three major parts. Chapters 1 and 2 comprise the first part, which states the importance of providing high-quality learning opportunities to support student learning processes in technology-based instruction and discusses crucial factors associated with engaging students in active learning processes. As an introductory chapter, Chapter 1 presents the critical issues of using educational technology to enhance student learning and explains why educational research must solve the issues.

Furthermore, Chapter 2 provides a broad theoretical framework for the empirical part of the present dissertation. The theoretical grounding starts from the comprehensive framework of the supply-use model, which provides a meta-level view of the complicated reciprocal relationship between teaching and learning (see Section 2.1). Building on this fundamental framework, I attempt to specify the teaching and learning condition that is prevalent in modern classrooms. Specifically, at the class level, I review how educational technology is used to supply learning opportunities and contribute to student learning (2.2).

Additionally, at the student level, the chapter specifically focuses on individual characteristics closely linked to successful learning (2.3). The constructs of intrinsic motivation, academic self-concept, and subject-specific prior knowledge are explored in detail, along with the empirical findings of previous literature. While retaining a focus on the student level, the next section discusses student involvement in learning processes by reviewing the crucial factors associated with active learning (2.4). This section explores how students' responses can be stimulated from emotion-motivational and cognitive perspectives by linking student involvement with active learning. To engage students with unique characteristics in active learning processes, teaching needs to be adaptive. The next section elaborates on the construction of adaptive teaching and discusses the influences of its three main compositions on student learning (2.5). Up to this point, the outlined theories of technology-based instruction and learning are still separate. Therefore, the following section bridges them by exploring the interplay between technology-based instruction and the student learning process (2.6). More specifically, I gather evidence from the existing literature that indicates the potential for technology-based instruction to (a) compensate for individual differences in learning, (b) support adaptive teaching, and (c) actively engage students in learning. By connecting existing learning theories and the use of technology, the second chapter provides a theoretical foundation for the empirical part of the present dissertation.

The second part is Chapters 3 through 6, which are devoted to empirical research. As discussed in Chapter 2, the changes in technology-based learning contexts require educators to reconsider student learning processes. However, a major issue in educational research is insufficient empirical research for uncovering whether or how technology can effectively support student learning. Thus, three empirical studies explore how students learn with educational technology. The three studies were embedded in the tabletBW research project, which systematically investigated the conditions and possible factors for the sustainable use of tablet computers in real classroom settings. Chapter 3 gives an overview of the research project and describes the general methodological approach of the three studies. This chapter aims to provide a methodological foundation in terms of study design, participants, data collection, and instruments.

Accordingly, Chapters 4, 5, and 6 present the empirical findings of studies with different research focuses on real classroom settings. In Chapter 4, the first empirical study (*Study 1*) assesses whether individual learning prerequisites affect student involvement (i.e., situational interest and cognitive engagement) in mathematics classes. Building on the relationship between prerequisites and active learning, this study further examined *when* (i.e., in which condition) the effect of individual learning prerequisites on the learning process would change. This chapter further discusses the effect of using tablet computers on the relationship between learning prerequisites and student involvement.

In Chapter 5, based on the significant effect of using tablet computers on student learning processes, a new question arises: whether the effect lasts over a prolonged period. To answer this question, the second empirical study (*Study 2*) investigates the association between technology integration in mathematics classes and changes in student involvement over time. The study then further explores whether the changes are affected by how tablet computers were utilized in learning. Assessing the quantity and quality of integration helps understand the mechanisms associated with the effective integration of technology and provides essential clues regarding how to impact student involvement over a prolonged period.

Moreover, Chapter 6 further explores tablet computers' potential in supporting adaptive teaching to understand *how* technology-based instruction affects the student learning process. Since the perception of instruction could reflect the students' learning experiences, the third empirical study (*Study 3*) examines the effect of using tablet computers on students' perceptions of adaptive teaching in the mathematics classrooms. Simultaneously, the study also investigates the mediation effect of perceived adaptive teaching on the relationship between using tablet computers and student involvement in learning processes.

Finally, the third part presents a general discussion. Chapter 7 summarizes and interprets crucial findings of the three empirical studies and compares them with previous studies (7.1). Furthermore, this chapter describes the strengths and limitations of the dissertation (7.2). After that, the implications for learning theories and classroom practices are discussed, and recommendations for prospective research in this field are provided (7.3). The chapter ends with an overall summary and take-home messages of the present dissertation (7.4).

2

Theoretical Background

Chapter 2 Theoretical Background

For a long time, people have argued that teaching and learning are different when it happens in traditional classrooms versus in the modern classroom (Mishra et al., 2009; Reiser & Dempsey, 2012; Sandholtz, 1997). This chapter comprises three-part with particular roles to explore the complicated interplay of teaching and learning. The first part provides a brief overview of a broad framework with a multilevel structure. This comprehensive structure prepares systematic guidance to review some critical factors and phenomena in 21st-century classrooms thoroughly. Rather than making an exhaustive review on all factors, the second part of this chapter integrates the relevant learning theories and concepts to the general framework. It focuses on some crucial factors—at both the class and student levels—that affect students' learning in a new classroom environment. The class factor limits the scope to ICT-based instruction and how this new teaching process can provide the opportunity to learn to students. Later, at the student level, this chapter focus on the factors that affect the use of learning opportunities: individual learning prerequisites and student involvement in learning processes. Among the reciprocal relationship in the classrooms, the central goal of instruction is to provide equal learning opportunities to facilitate all students' learning. These equal opportunities cannot be achieved without accommodating the differences in individual learning prerequisites. In response to this, the concept of adaptive teaching and its importance for student learning is elaborated here. Building on the review of class factors and student factors, the last section of this chapter discusses the interaction between the supply and the use of learning opportunities by bringing up the concept of adaptive teaching.

2.1 Multilevel Supply-Use Model

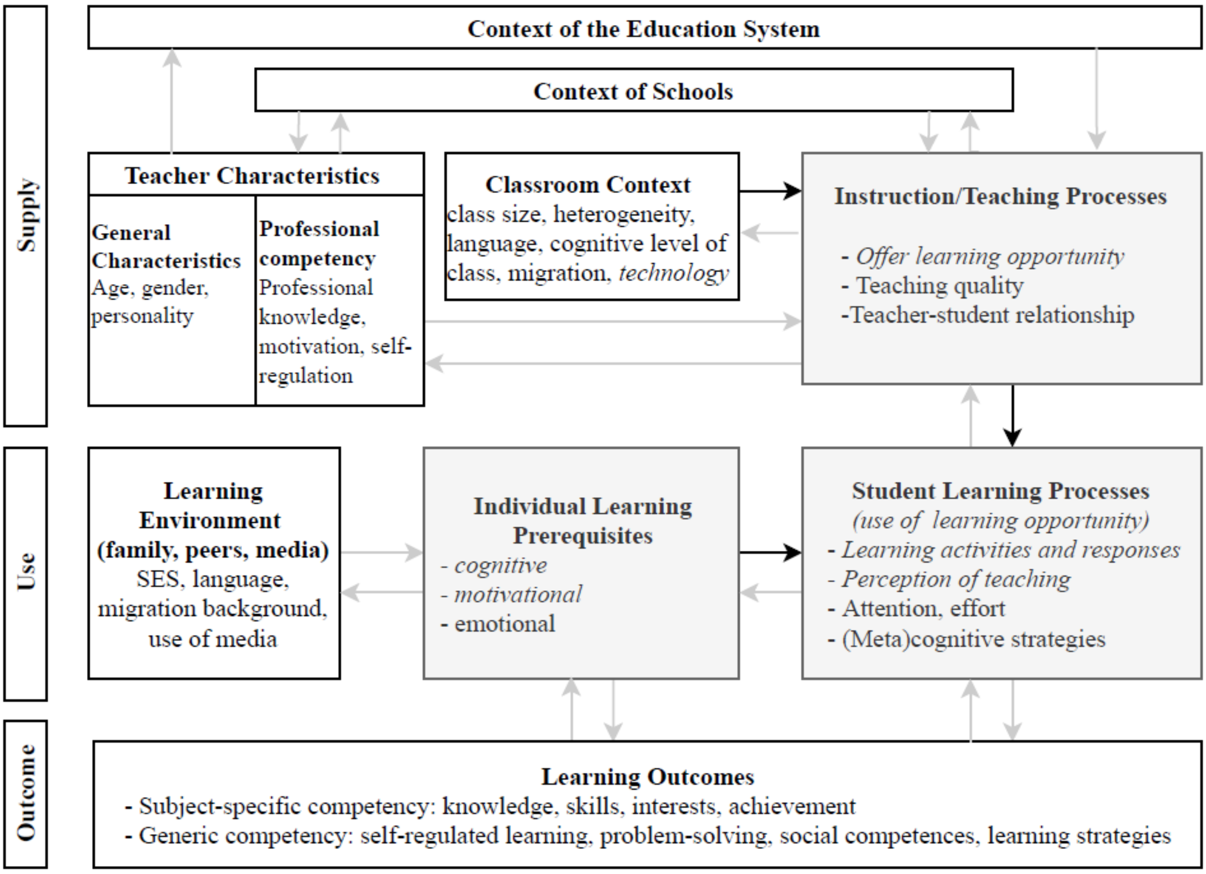
In recent decades, a great deal of attention in educational research has been focused on identifying learning processes by developing a better understanding of how individuals learn in school settings. Different models have been developed and are available to explain student learning in specific educational contexts. In the early 1980s, researchers started using the process-product model to discover the relationships between what teachers do and what students learn in the classroom (Brophy & Good, 1984). This model provided a causal one-direction model to explain the effects of teaching on student achievements. However, the early studies based on the simple direct model underestimated the impact that other classroom practices had on student learning. The focus of many of these studies (e.g., on teachers' behaviors in class, on student achievement) could not explain the black box that contained students' learning processes. By conducting a meta-review, Wang et al. (1990) synthesized six categories of variables related to school learning, such as student characteristics, classroom instruction, and school-level variables. Therefore, to have a systematic understanding of student learning, it is necessary to develop a more comprehensive and fundamental model to explain the complicated interplay in classrooms.

To provide a vivid explanation, Fend (1982, 2019) used a metaphor (i.e., supply and use) to point out the relationship between teaching and learning in schools. He assumed that student learning is a process of using opportunities that are offered by teaching and instruction. Based on this assumption, he introduced the supply-use model (Angebots-Nutzungs-Modell). Subsequently developed by many other scholars, this has become an influential framework widely used to explain teaching and learning, especially in German-speaking countries (Brühwiler & Blatchford, 2011; Helmke, 2007; Seidel et al., 2016). Building on this model, some researchers have integrated educational sciences with psychology research perspectives (Kunter & Ewald, 2016). Some other researchers have adapted this framework and have narrowed it down to particular constructs and concrete contexts, such as instructional quality in higher education (Seidel, 2014b) and class size effects in primary schools (Brühwiler & Blatchford, 2011).

With a progressive evolution, this model has gone through several revisions in both name and structure. During the evolution, the name of the supply-use model has also been translated differently, such as the offer-and-use model (Kohler & Wacker, 2013), the opportunity-to-learn model (Seidel & Reiss, 2014), and the offer-take-up model (Göbel & Helmke, 2010). These different terms have usually been interchangeable in previous literature. In addition to variation in terminology, the model has been adapted to explain different macro- and micro-level factors that affect student learning across various educational contexts. Eventually, the recent version came to cover the majority of components that are associated with school learning. The factors have been systematically categorized into three levels: (a) supply level, (b) use level, and (c) learning outcomes level. In the meantime, the structure of the model is framed in terms of personal, class, and environmental factors that explain the interaction happened while student learn. Figure 2.1 provides a visual representation of the reciprocal relationships between different variables or constructs. The effect of these factors can go either from top to bottom or from bottom to top. The three levels constitute a complex framework that can be used to explain student learning comprehensively.

Figure 2.1

Multilevel Supply-Use Model of Student Learning in School



Note. Adapted by permission and copyright received. From "Effects of class size and adaptive teaching competency on classroom processes and academic outcome," by Brühwiler, C, and Blatchford, P, 2011, *Learning and Instruction*, *21*, p. 95-108. The italic variables in the greyed blocks are the key components investigated in the present dissertation. The fundamental relationships are indicated with bold arrows.

Specifically speaking, the supply level of the model comprises a variety of teaching-related factors that affect student learning at either the macro-level (e.g., education system) or the micro-level (e.g., school and classroom context). According to Seidel and Shavelson (2007), teaching is considered as a learning opportunity involving complex situations that may provide various learning time, materials, or specific activities to students for learning. The micro-level concentrates on the optimal use of opportunities offered by schools and teachers. The opportunity refers to students' chances to improve their learning competencies and engage in the amount of time allocated for learning (Greeno & Gresalfi, 2008). Besides, the opportunities may vary because of different teaching methods, strategies, and technologies used to address student learning needs (Corno, 2008). Substantial studies claimed that quality teaching in schools matters for student learning, and it ensures students with diverse learning prerequisites can benefit from formal education (Fauth et al., 2014). In particular, the instructional design and classroom processes should accommodate students' learning and motivational needs (Heller, 1999). At this supply level, the model reveals that to deliver learning opportunities to students successfully is challenging because it relies on a complex interplay among factors such as the sensitivity to student heterogeneity, appropriate didactic methods, quality of instruction, and teaching-learning materials. In this sense, teaching and instruction do not automatically lead to positive effects on student learning processes. It largely depends on students' background, their learning prerequisites, and their perception of instruction. In a similar vein, learning relies on meaningful interaction of the individual students (i.e., use) with teachers and instruction (i.e., supply).

The use level of the framework outlines the crucial factors that associate with the effective use of the opportunity to learn. In particular, understanding the effects of the individual characteristics on student learning is a persistent concern of this model. These student characteristics are expected to impact that person's perception toward the teachers and instruction. In return, teaching and instruction contribute to student learning by providing learning time, materials, or activities (Helmke & Schrader, 2013; Kunter & Trautwein, 2013). Building upon this reciprocal relationship, the connection between the supply and use level is firmly established. Rather than directly influencing student learning, the learning opportunity is mediated by the individual perception and their interpretation of the teaching. In this vein, for teachers, the challenge arises to provide learning opportunities that elicit active and meaningful learning processes for all students. In response to this, the use level of the current model emphasizes the role of student characteristics, perceptions, and learning behaviors. These student factors are treated as the prerequisites or preconditions of further learning (Bransford et al., 2000). The student's different learning potentials and prerequisites affect the utilization of the learning opportunities offered during the instruction. Additionally, the supply-use model stresses that the teaching process also does not fully account for student learning. During an instruction, learners' perception and interpretation of the lesson mediate the relationship between the teaching process and the learning process. Specifically speaking, the learning process reflects how students perceive the learning opportunities given by their teachers in the instructions.

Finally, the outcomes level is at the output end of the learning process. There seems to be general agreement in academic settings that the learning outcomes multidimensional and can be classified into cognitive, non-cognitive, and meta-cognitive outcomes (Brühwiler & Blatchford, 2011; Kraiger et al., 1993). The empirical study in educational science frequently focuses on evaluating effective learning by assessing their outcomes (Gagne, 1984). Especially the cognitive learning outcomes, such as students' academic performance and cognitive abilities, have attracted close attention from researchers. In classroom practices, there is no doubt that cognitive learning outcomes (e.g., verbal knowledge, cognitive strategies) are the critical indicators of the effectiveness of teaching and learning processes (Ackerman, 1986, 1987). Individual development in cognitive abilities is necessary, but not the only goal for student learning. Thus, this dissertation primarily focuses more on learning processes and the critical factors involved in the processes.

As described earlier, this model provides a comprehensive explanation of the complicated reciprocal relationships relevant to student learning. Nevertheless, as a dynamic process, changes happen in student learning during the interaction with new techniques or teaching approaches. When more advanced educational technologies are introduced to schools, learning with technology has become a remarkable feature of modern education. It is essential to effectively integrate technology and how technology is associated with the learning opportunity in this situation. However, in addressing the critical issues of technology-related teaching and learning, the supply-use model may not provide a thorough explanation. More importantly, a comprehensive understanding of how to effectively implement technology as a part of instruction and its effect on students' opportunity to learn is still lacking. Therefore, the current chapter begins with the multi-level structure of the supply-use framework. Using it as a theoretical foundation, more critical issues of student learning in the 21st-century classrooms would be addressed and explained.

2.2 Class Level: ICT-Based Instruction

"Technology will never replace great teachers, but in the hands of great teachers, it's transformational."

—George Couros

When unfolding the theoretical structure of the supply-use model, the teaching process is one of the vital components on the class level. According to this framework, the teaching process mainly involves three dimensions: instruction quality, the number of learning opportunities, and the teacher-student relationship (Brühwiler, 2014). Previous researchers have been concerned with each of these aspects for a long time. In recent decades, with technology development, some tremendous changes have occurred in learning environments (Reiser & Dempsey, 2012). However, when technology is situated in the teaching process, the interplay between technology and learning processes has remained unclear (Hennessy et al., 2005). To better understand the teaching process in 21st-century classrooms, the following section adapts the original class factor of the supply-use model and expands into technology-based instruction.

2.2.1 Integrating Technology in the Classrooms

Learning is situated on a particular occasion and cannot be isolated from the classroom environment (Anderson et al., 1996; Greeno et al., 1996). Since the 1980s, people have advocated for using various teaching and learning techniques in classroom environments (Cuban, 1988; Tolhurst, 1995). What is the educational technology? Initially, in education, information, and communication technology (ICT) was defined as a medium that could be used to deliver learning materials and support the learning process (Luppicini, 2005). With advanced development, ICT has evolved into being incorporated into different digital devices to establish active learning (Rocci, 2005; Vila Rosado et al., 2016). Based on the application scope, the term ICT is interchangeable with some alternative terminologies such as educational technology and instructional technology (Januszewski & Molenda, 2013; Seels & Richey, 2012). For instance, Braham (1977) conceptualized educational technology as an organization of activities designed to assist a person's adaptation to, participate in, and utilize the environment.

Contrary to the idea that technology can support teaching and enhance student learning, ICT-based instruction emphasizes how to integrate and implement particular digital tools based on the teaching goals and learning needs. The design of ICT-based instruction and the use of technology need to engage students with various learning characteristics. This definition used in this dissertation highlights the reasons for using technology to accommodate the diversity of student learning requirements and engage students during the learning processes. For the present chapter and rest of the dissertation, a distinction between the ICT-based instruction, which refers to the use of technology while teaching and learning in the classrooms, and the concept of the ICT-based classroom environment (Bottino, 2004) or the digital tool per se (Keengwe et al., 2008) is important.

Similar to the previous definitions, which emphasized the character of the ICT-based instruction, the term of technology-enhanced learning (TEL) refers to the process of implementing technology to better support student learning or even transforming an individual's educational experience (Chan et al., 2006; Laurillard, 2008). The concept of technology-enhanced learning was taken on board because of the appearance of a new generation of students who were born in an environment surrounded by digital tools and technology (Ainley et al., 2008; Palfrey & Gasser, 2010). Facing the changes in students, teaching should also prepare for the new generation of "digital natives" to achieve appropriate development in the digital age (Fishman & Dede, 2016). The design of teaching and instruction is encouraged to be consistent with the new generation's learning requirements, such as enhancing their advanced technology literacy skills (Ng, 2012). By promoting the technology-enhanced learning in school settings, more shreds of evidence showed that this instructional approach significantly changed the classroom environment and contributed to student learning (Price et al., 2005). Nevertheless, not every application of technology leads to a positive impact on learning processes (Lei, 2010), especially when a mismatch appears between the provided features and students' learning needs. In order to see what kinds of contribution digital tools could make to student learning, it is necessary to take a brief overview of the available technology for educational purposes.

Old and New Digital Media in Classrooms. Technology has been used for educational purposes in classrooms for over 100 years. As early as 1920, digital media entered classrooms in the form of, for example, radio, film, and instructional television (Buckingham, 2007). It was viewed as a symbol of progressive teaching. However, these old digital media were not used very frequently in a wide range. The primary reasons were a lack of equipment, difficulties integrating these media into the school schedule, plus a lack of technological knowledge on the part of the teachers (Cuban, 1986). In addition, the old digital media had few advantages over conventional teaching approaches. Many of their technological features (e.g., projecting pictures, merging audio and visual information) applied in the classroom are not innovative. The paper-based textbook and the blackboard could replace these functions. Therefore, without any superior characteristics beyond the traditional instructional approach, the application of old media did not lead to a transformative change in teaching and learning.

Nowadays, compared with the last century, educational technology has changed many aspects of teaching and learning (Pelgrum & Plomp, 1993). Due to technology development and interdisciplinary cooperation, new tools have been developed for teaching. Introducing new tools and technologies in classroom processes brings their corresponding potentials and distinctive features to teaching and learning. For instance, the technology revolution has enabled technology to generate automatic analyses and provide students with automatic feedback. For instance, the Feed-Book program is implemented to provide adaptive feedback to individual language learners based on their answers (Scheiter, 2017). The above examples of the potential for adaptive teaching remain at the micro-adaptation level based on a continuous following of student learning states. Because new media has the potential to infuse innovative approaches into instruction, they should be encouraged in teaching and learning. Simultaneously, the broad access to ICT has stimulated an increase in the volume of research on effective integration.

One-to-One Computing. In the late 20th century, access to computers in schools was limited. Personal computers were not as visible as they are today. For instance, in 1998, when we asked teachers and students in U.S public schools how many computers they had in their schools, students' reported ratio to computers with Internet access was 12 (NCES, 2000). Since 2009, according to the statistics on ICT integration, the number of computers used in schools and individuals classrooms has steadily increased (OECD, 2015b). For instance, some American schools have strived to make computers accessible to every student (Cuban, 2009). Hence, the last two decades have witnessed a distinct implementation of computers across educational contexts. Nowadays, it is more common to see the use of personal laptops in the learning environment.

One-to-one computing setting refers to a technology-rich environment in which teachers and students have ubiquitous access to personal computers (Bebell & O'Dwyer, 2010; Zhai et al., 2016). When students do not need to share digital devices during their classroom routine, the frequency and variety tend to increase. One-to-one computing creates a new classroom context to enable teachers and students to explore a broad range of subject-specific (e.g., Mathematics, English, and Science) learning activities (Zheng et al., 2016). Furthermore, the one-to-one computing was found to attract student attention, inform objectives, stimulate prior learning, present content, provide learning guidance, activate practice, provide feedback, assess performance, and enhance retention (Bruner, 1963b; Gagné et al., 1992). Moreover, the implementation of one-to-one technology was revolved to significantly enhance student learning by strengthening the connection between student and situation (Chan et al., 2006). Building on this positive potential, more one-to-one computing settings have been integrated into students' learning experiences, such as mobile devices (e.g., tablet computers, smartphones).

Mobile Devices. Among a variety of devices available inside and outside the classroom, the number of one-to-one mobile devices (e.g., mobile phones, laptop computers, and tablet computers) has recently increased in school settings (Sung et al., 2016). Some of them were implemented in the core school subject classroom (Handal et al., 2013). Particularly, tablet computers (e.g., iPad) have become more affordable for schools, and the popularity of tablet use is enhanced rapidly (Falloon, 2013; Major et al., 2017). These new types of digital equipment have several significant characteristics superior to desktop computers or any other old digital media (Mango, 2015). The first unique feature is portability (Courts & Tucker, 2012). For instance, when working with tablets computers, students are allowed to move to different classroom sites. Moreover, the feature of portability broadly expands the students' learning space and increases the possibilities to attend different types of activities (Csete et al., 2004; Fu, 2013). Secondly, mobility enhances the interactions and collaboration between students (Klopfer et al., 2002). It is essential to underline that better communication and disclosure between mobile devices users contribute to the second feature (Bofill, 2013). While the introduction of mobile devices continues, on the one hand, recent studies focus on the contribution of these new tools to students' academic achievement (Sung et al., 2016). On the other hand, recent research pays attention to the effect of these new digital tools on learning processes such as student engagement (Diemer et al., 2012) and the effect of learning interest (Walkington, 2013). Based on the brief view of the available digital tools applied in school settings, educational research has enduring attention to the relationship between the integration of technology and student learning.

Use of Technology and Learning. In educational research, the number of studies about the critical issues of using technology on learning has been increasing (Lepper, 1985; Reiser & Dempsey, 2012). Alongside the broader use of modern one-to-one mobile devices in the classroom, the contribution of technology to student learning has an enduring attraction in the discussion of modern education (Mishra et al., 2009). On the one hand, technology is assumed to provide specific potentials for enhancing teaching and learning processes in classrooms (Grabe & Grabe, 2008). Hattie (2009) synthesized 81 published articles and evaluated the effect of using technology for learning purposes. He found that technology generally positively affected student learning outcomes (e.g., student achievement, student engagement, students' positive attitudes toward learning and schools), with a medium effect size ($d = 0.37$).

Furthermore, technology in meaningful learning contexts in schools has been identified and emphasized as a significant priority across countries (OECD, 2015b). When the attention shifts to particular instructional activities, some studies have also claimed that technology can significantly advance student learning by providing adaptive feedback and immediate responses (Hattie & Yates, 2014b; Mayer, 2003). In many ways, technology supplements traditional teaching and expands students' educational opportunities to different learning extents (Bauer & Kenton, 2005). Even with considerable positive shreds of evidence of technology integration, the real effect in learning is still under debate (Clark, 1983; Clark, 1994). More discussions of the interplay between the use of technology and other factors in learning processes are presented later in this chapter (see 2.6). Before that, since the implementation of technology is impossible in the absence of educational context (Berliner, 2002), the next section describes the situation of using technology in mathematics education.

Use of Technology and Mathematics Education. In an academic setting, teaching and learning often take place in a subject-specific or domain-specific situation. Because in teaching different subjects, there is a wide variety of differences in teaching strategies, materials, learning tasks, and activities. In a similar vein, the use of technology is usually situated in the core school subjects, such as mathematics, English, and science learning (Hu et al., 2018; Pearson et al., 2005). In particular, previous research pointed out a decline in secondary school students' academic interest toward mathematics learning (Frenzel et al., 2012). This phenomenon is closely related to the unique stage of interesting development during adolescence (Hidi & Renninger, 2006). Not only the students but teachers are also struggling in promoting their students' positive feelings and favorable attitudes during mathematics learning. In traditional classrooms, teachers have devoted large efforts to motivate the students and enhance engagement. But still, school students reported anxious, unmotivated, and other negative responses when anticipating the mathematics tasks (Lyons & Beilock, 2012).

In response to students' low interest and negative feelings in mathematics learning, educators and researchers have devoted many efforts to discover the effective strategies and techniques to trigger students' curiosity and motivation (Hoyles & Lagrange, 2010). Among those old and new approaches that recommend assisting in teaching mathematics, technology was found to have distinctive potentials and features on facilitating student learning (Haddad & Jurich, 2002; Scheiter, 2017). Some previous studies had shown a high interest in exploring the use of educational technology in mathematics education (Heid, 2005; Li & Ma, 2010). Many educational researchers have attempted to investigate any effective approach to facilitate mathematics learning with technology (Goos et al., 2003; Kulik, 2002).

After narrowing the focus on integrating technology into mathematics education, numerous alternatives target to support a single school subject (Mayer, 2003). Recent studies examined different types of subject-specific tools and techniques that suitable for mathematics learning, such as a game-based program to develop students' numerical skills (Yeh et al., 2019), The findings of the above study supported that new technology is in many ways changing students' mathematics learning for the better. Although substantial tools and programs have been designed for school subject mathematics, their effectiveness and potentials are not independent of the users' professional knowledge of technology and subject matter (Koehler & Mishra, 2009). Additionally, to achieve the best use of new tools for education, the integration process should closely relate to the teaching purposes and classroom activities (Price et al., 2005). Based on the real settings and specific learning needs, the technologies are integrated to support teachers accordingly. Nevertheless, when teachers attempt to integrate new tools into classes, they may face many potential challenges such as lack of training opportunities, lack of practice with new devices, and lack of technical support (Donnelly et al., 2011; Kopcha, 2012). More importantly, many teachers have limited knowledge of how to integrate technology with particular classroom activities to achieve the teaching goal (Koehler & Mishra, 2009). Additionally, before discussing the impact of using technology on student learning, it is natural for teachers and educators to ask how technology can be integrated into the classroom as a learning tool. Therefore, it is important to elaborate on the mechanism of technology integration in classroom environments. The following section provides an overview of two models that distinguish ICT integration levels and their related learning activities.

2.2.2 Levels of Integration

According to Clark (1983), the determinant of effective educational technology implementation is the method and not the tool per se. Because the technology or digital devices are unstable and ever-changing (Koehler & Mishra, 2008), the effect of ICT-based instruction in learning is strongly associated with how the technology was integrated into different classroom activities (Petko et al., 2017). Therefore, rather than comparing different technological tools or devices, prior findings regarding technology in instruction have also focused on using it (Scheiter, 2017). Based on this argument, the following paragraphs present two models that can be used to clarify different levels of technology implementation for educational purposes and determine whether technology can contribute to a complex cognitive process.

The Replacement Amplification, and Transformation (RAT) Model. In exploring the use of technology within the educational context, Hughes (2000) introduced an assessment framework to explain technology's role in teaching and learning processes. Initially, she developed the model to categorize the roles and characteristics of technology used to support English teaching in schools. In this model, the integration of technology was differentiated into three levels: technology as a replacement (R), technology for amplification (A), and technology for transformation (T). This model's underlying argument is that technology is used as a digital tool to serve teachers' pedagogical and curricular goals (Mitra, 1998). Based on the particular teaching goal, teachers choose to use different technologies.

Specifically speaking, when technology only replaces the traditional approach without changing any instructional methods, it is placed in the replacement dimension, such as replacing paper-based textbooks with digital books. At this basic level, digital devices' implementation merely changes the presentation format of the information, but without any functional enhancement. Second, when technology is integrated for amplification, it significantly enhances the original instructional practices' efficiency and effectiveness. For example, different from superficial changes, teachers choose the software program to prepare learning materials, examinations, or other administrative processes. This second level of implementation significantly promotes the efficiency of instructional preparation.

The third level of implementation is transformation. Rather than making a slight change in teaching processes, technology as transformation involves a change in instruction that would never be possible without technology, such as visualization and simulation tools in a real scenario. At this level, technology is used in an innovative or redefining way. This advances type of implementation that empowers teaching and learning, which is impossible without technology. Based on this implementation model, educational researchers continuously seek more possibilities to link technologies to students' higher-order thinking and provide appropriate instruction for students (Levine et al., 1987; McMahon, 2009). When accompanied by more innovative features, technology has the potentials to provide personalized instruction and transforms teaching into an adaptive format that cannot be applied in the traditional classroom (Haddad & Jurich, 2002; Murphy & Davidson, 1991). This degree of change restructures and reorganizes students' learning processes (Pea, 1985).

The Substitution, Augmentation, Modification, and Redefinition (SAMR) Model. Puentedura (2003) introduced a four-level model primarily to illustrate how educational technology offers teachers and students a practical approach that can be applied to perform different levels of tasks. Different from the RAT model, which distinguished the use of technology into three categories, Puentedura conceptualized the integration of technology as covering four areas: substitution (S), augmentation (A), modification (M), and redefinition (R). When further evaluating its use to support learning, the previous two levels were synthesized into the enhancement category, whereas the latter two belong to transformation (see Figure 2.2).

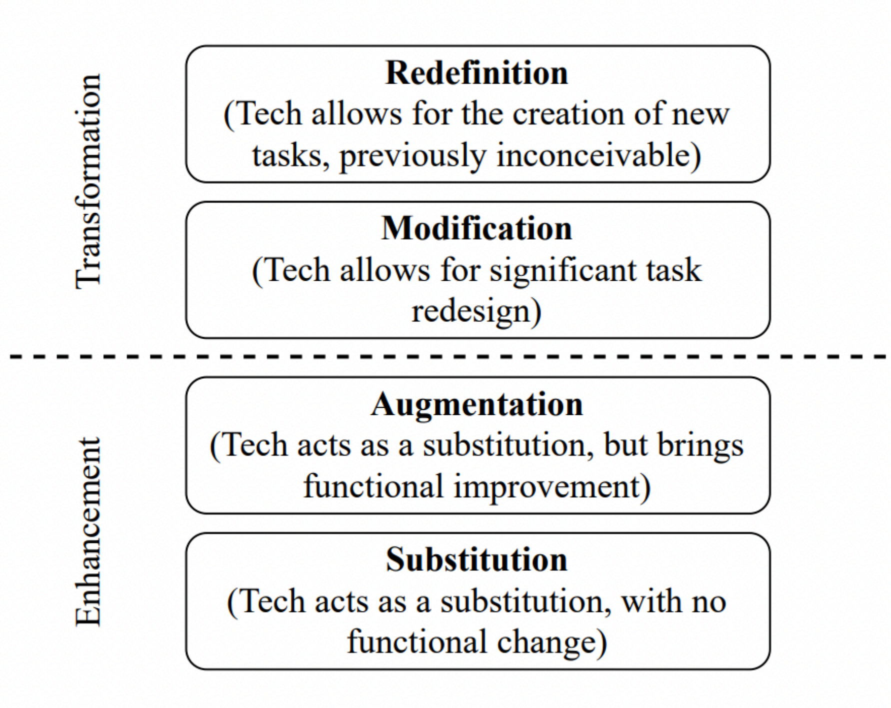
Once a technology or digital tool is introduced in the classroom environment, the most basic implementation is to use it for simple replacement. Instead of using the paper-based textbook or worksheets, teachers and students can highlight the key concepts in a digital file. However, the drawback of this type of implementation is the users can perform the same tasks possible without using technology. This implementation level frequently appears when technology is newly introduced in the learning environment where teachers have limited knowledge of how to adapt it (Koehler & Mishra, 2009). When the selection moves from substitution to augmentation, technology is used to enhance teaching efficiency and effectiveness. For instance, students can work with the electronic dictionary program, which accelerates the searching process and avoid the spelling problem. The second level of implementation provides some functional improvement for teaching and learning processes.

The third level is the modification, which has a distinctive feature to redesign a learning task (Hamilton et al., 2016). For example, using simulation games in combination with real-world mathematics problem-solving tasks can lead to higher order thinking in individuals. The students are aided by the vivid presentation and experience the interactive learning process at their pace. The highest implementation level is redefinition, which has the most innovative use that is inapplicable without technology. For instance, the use of technology (e.g., flipped classroom) at this level can assist the project-based mathematics learning, which facilitates innovative learning (Wang et al., 2014) and student engagement (Rahman et al., 2015).

Additionally, the novel techniques can also create individual assignments or learning tasks for the student. (Hamilton et al., 2016).

Figure 2.2

SAMR Model



Note. Adapted by permission and copyright received. From "SAMR: Getting to transformation," by Puentedura, R. R, 2006 (http://www.hippasus.com/rrpweblog/archives/2013/04/16/SAMRGettingToTransformation.pdf).

When students use technologies at a less sophisticated level, these are applications of enhancement. Although the use of technology at enhancement level is possible to be replaced by an alternative teaching approach, users (i.e., teachers and students) feel safe and confident while working with the technology (Chell & Dowling, 2013). Pulling further up the implementation ladder, technology can and should be used to perform more complex classroom activities. Additionally, Puentedura (2019) assumed that when the activities and tasks shift from enhancement to transformation, the effect of technology integration on learning is enhanced. However, prior studies have reported that technology has more often served as either a supplement to or a substitute for traditional teaching (Kulik & Kulik, 1991). Although the opportunities to use technology are increasing, its effects on student learning cannot be activated without teachers who know how to carry out the proper use of technology (DeCoito & Richardson, 2018; Marcinkiewicz, 2014). Technology is supposed to support teachers instead of replacing them (DeCoito & Richardson, 2018). In sum, this four-level theoretical framework clearly describes the rank of teaching with technology. It was widely applied to provide useful clues for teachers to design classes with digital tools in classrooms (Hamilton et al., 2016). Following the path, the current model offers educators the opportunity to locate their operation of technology and simultaneously reflect the degree of digitization of the classroom.

However, how to apply the SAMR model in concrete teaching and learning activities remains unclear (Hamilton et al., 2016). In response to the gap, it is necessary to situate the model in a particular educational context. For instance, when introducing technology into mathematics classrooms, educational researchers have begun to investigate whether computers contributed to mathematics learning (Dynarski et al., 2007). Prior research discovered that technology is gradually changing the nature of teaching and learning in this academic subject (Wiest, 2001). Particularly, at the enhancement level, when computers replace paper-and-pencil calculations, students spend less time on algebraic calculations. Instead, lesson time can be put toward higher-level learning activities such as simulation or reasoning (Louw et al., 2008). Additionally, when teachers leave more time to spend on computer-based simulation games, it provides opportunities for students (Gros, 2007; Sitzmann, 2011). Relative to other instructional approaches, the transformative type of computer-based activities promotes deep learning (Petko et al., 2017). From the prior research, it is clear that technology can be integrated for different educational purposes and, in turn, affect the effectiveness in supporting teaching and learning. On the one hand, these previous studies emphasized the hierarchical continuum movement to effectively support teaching and learning. On the other hand, early studies indirectly pointed out the importance of integration quality. There are some debates on how different types of integration affect learning.

Mechanisms of Integration. When unfolding the integration mechanism of technology and digital tools, they have changed teaching and learning processes from two aspects. First, integrating technologies has influenced the quantity and quality of learning opportunities offered by teaching (Lei, 2010; Petko et al., 2017). On the one hand, the quantity of learning opportunities appears in the time spent in learning tasks and activities during instructions. Specifically speaking, in ICT-based instruction, the amount of time that teachers and students spend on working with tablet computers is treated as the quantity of the integration mechanism. Imaging students who have learned with traditional materials such as paper-based textbooks and worksheets for a long while, the newly introduced technology and the digital tool would bring them a new learning experience in classrooms. As a motivational factor, on the one hand, this *novelty* was found to positively affect student engagement and persistence in using new technology. On the other hand, it is important to notice that the novelty effect may dilute the real effect of using technology to support teaching and learning. According to Clark's meta-analytic study (1985), he also pointed out that the effect of technology occurred in short-term integration and not extend to a prolonged period of learning.

Furthermore, the report of nation-wide student assessments (i.e., PISA studies) revealed that students with the highest using frequency of computers did not significantly perform better than the students without frequent use (Schleicher, 2005). The process of adopting novel technology (i.e., diffusion of innovations; Roger, 2003) explained this nonsignificant relationship (Shin et al., 2019). That is the students' excitement and other positive attitudes toward using technology decreased after the novelty period. Furthermore, the novelty effect of using technology did not associate with students' self-determined intrinsic motivation in learning (Jeno et al., 2019). In this sense, if only promote the amount of use or rely on the innovative application, the implementation of technology at schools did not imply a long-term adherence positive effect on learning.

Compared to the quantity of technology use, recent research suggested that the quality of technology is a more significant impact on student learning (Alexander, 1999; Hedberg, 2002; Lei, 2010). During instruction, the integration of educational technology involves different classroom activities and serves particular objectives. Therefore, the quality of using technology is a complicated issue that seems difficult to evaluate and promote. From the constructivists' perspectives, the student-centered learning process is the underlying reason for the effective and high-quality classroom activities (Chou, 1998; Duffy & Cunningham, 1996). In this sense, if the characteristic of particular technology-based classroom activity meets student-centered requirement, it constitutes high-quality activity and contributes to effective learning. Boud and Prosser (2001) introduced several criteria to qualify the student-centered classroom activities so that to better evaluate the quality of technology integration. For one, high-quality technology-based learning activities enhance student engagement through acknowledging and considering individuals' prior knowledge and learning experiences. For example, when using technology to assign high-quality learning tasks or homework, the students' level of understanding, and their will should be considered (Dettmers et al., 2010). Besides, Boud and Prosser also emphasized the involvement with problems in context. This argument was confirmed by investigating computer-based simulation activities (Ravert, 2002; Sitzmann, 2011). Computer-based simulation generally refers to a set of learning tasks delivered in an artificial environment to promote students' reality-based problem-solving skills

(Vogel et al., 2006). The subsequent research found that computer-based simulation and instructional context characteristics effectively conveyed the knowledge and motivated the student learning. Taking together, to go beyond the novelty effect, technology should be embedded in high-quality classroom activities and contributes to students' active involvement in learning processes.

In short, this section adopts the integration of technology to the initial supply-use model by exploring the interplay of teaching and learning processes in the context of ICT-based instruction. Exploring the potentials and roles of ICT in the 21st-century classroom provides the theoretical support to the crucial role of this new teaching processes on student learning and the elements relevant for effective integration. More discussion about the links between ICT-based instruction and student learning will be left for the last part of this chapter (Section 2.6).

2.3 Student Level: Individual Learning Prerequisites

By unfolding the critical factors in the class level, the previous section specifies a new alternative approach for teachers to provide optimal learning opportunities. As this alternative occurs, integrating technology into different levels of classroom activities was discussed as well. More importantly, in the ICT-based instruction, students play the central role in their learning processes, which means they are the primary entity of using the opportunities. View in this way, moving from the class level to the individual level of the supply-use-model, this student-centered idea is also treated as the fundamental argument. According to the relationships addressed in the model, students' learning prerequisites form an essential factor influencing how students perceive and use learning opportunities. To better understand the learning process, student characteristics need to be examined. Therefore, this section is about the student characteristics that need to concern during student learning.

2.3.1 Individual Differences in Learning Prerequisites

Within a classroom, the way and extent of students perceive the teaching and instructions vary from one person to another. These differences affect how they use the opportunities they are given. It is common to observe the phenomena that individual students are unique within the same class, and they exhibit differences in their emotional, motivational, and cognitive characteristics (Kunter & Trautwein, 2013; Snow et al., 1996b). For instance, students may come to the class with different levels of interest in mathematics. Even if the students are interested in mathematics to similar extents, some may learn faster than other classmates. The goal of achieving effective instruction cannot be validated without understanding individual characteristics in learning.

Among the broad range of student characteristics, some are the prerequisites that significantly contribute to learning processes and outcomes. Numerous learning theories and models seek to identify the essential student characteristics that predict student learning behaviors and activities in classroom settings. Concerning the wide variety of learning prerequisites, the current section can only be selective and provide a more in-depth discussion of students' motivational and cognitive prerequisites for learning. It explicitly focuses on three aspects of individual characteristics: academic motivation and interest, academic self-concept, and prior knowledge by clarifying their conceptualization, principal components, assessment approach, and importance for student learning.

The primary reasons for focusing on the above three individual learning prerequisites are as follows: First, previous studies in educational sciences and psychology have revealed that a student's motivation, interest, academic self-concept, and prior knowledge are crucial factors are closely related to successful learning (Murphey & Joseph, 2013; Wang & Lindvall, 1984). Most of these crucial factors are not directly observable during the instruction, leaving much space to further explore. The understanding of these factors uncovers the learning process at the level of individual students.

Second, when concerning the stabilization of student learning prerequisites, early research suggested that many of these characteristics can change as students interact with a complex environment (Murphey & Joseph, 2013) and can be improved through schooling (Broudy, 2016). In particular, a great deal of research has found the state character and changes in students' motivation and interest (Bailey et al., 2014; Frenzel et al., 2012; Hidi & Renninger, 2006; Plenty & Heubeck, 2013; Ryan & Patrick, 2001; Stage & Williams, 1990), academic self-concept (Gest et al., 2005; Marsh, 2014), as well as prior knowledge (Bjorklund, 1987). These empirical findings could mean that many of the learning characters can be modified by experience.

Third, if we look closely at the context of the three prerequisites, all have characteristics associated with subject-specific learning experiences (Brophy et al., 2001; Marsh et al., 2006). On the one hand, subject-specificity is appropriate for a comprehensive understanding of these constructs with a broad and sophisticated research history. On the other hand, the domain-specificity is in line with the focus of the present dissertation on exploring student learning in mathematics classroom environments. Thus, to better understand the student learning process, knowledge of the individual characteristics needs to be considered as preparation for reaching this objective.

The following section focuses on each of the three individual learning prerequisites and simultaneously addressing some critical issues: (a) What is the definition, and how is it identified in the early learning theories or models? (b) How is the individual learning prerequisite relevant to student learning processes? (c) How can individual learning prerequisites be measured? And (d) How can it be improved in classroom environments?

2.3.2 Academic Motivation

Students from the same class are not equally motivated, which results in individual differences in motivation. But what is motivation? In a generic sense, motivation is a central concept in educational psychology that helps people understand and explain why they behave differently (Kleinginna & Kleinginna, 1981). In previous literature, this noncognitive factor is not neglected as long as researchers discussed the topic of individual learning. Research on this topic acknowledged and brought advancing theories for a better understanding of this concept. Early theories suggested that motivation is a multifaceted construct. One of the key theoretical frameworks that have influenced a considerable amount of research is self-determination theory (SDT; Deci & Ryan, 1985).

When uncovering the complex concept of motivation, Deci and Ryan (1985) introduced SDT to distinguish between types of motivation that are particularly relevant to student learning. SDT classified the concept of motivation into three types: intrinsic motivation, extrinsic motivation, and amotivation (Vallerand & Ratelle, 2002). According to SDT, when a student is learning for pleasure, curiosity, and inherent satisfaction, their learning is driven by intrinsic motivation. The student's motives come from the activity itself, and the action is self-determined or self-directed (Corno & Rohrkemper, 1985). A previous study also confirmed the connection between interest and learning behaviors (Schukajlow et al., 2017): When students perceive the topic of Pythagorean theorem interesting, they are willing to learn more about this mathematical topic. Comparatively, when a student's learning behaviors are triggered by external outcomes (e.g., praise or rewards), SDT attributes it to a person's extrinsic motivation. The learner's motives are from outside and are not self-determined. In contrast to the previous types of motivation, Deci and Ryan also posited the concept of amotivation (i.e., does not motivate at all). When a student is amotivated, this person generally has neither intrinsic nor extrinsic motivation to participate in any learning activities. It is important to notice that this lack of motivation was identified as an unresolved issue in education for a long while (Hidi & Harackiewicz, 2000).

Building on the macro theory of motivation, the concept of academic motivation is multidimensional (Martin, 2007) and can be further classified into domain-specific or subject-specific construct (Murphy & Alexander, 2000). *Motivation in mathematics learning* particularly refers to students' positive emotional valences and task interest (or liking) in school subject mathematics (Renninger et al., 2014). Different from other student characteristics such as personality that tends to be evaluated in general, research in particular subject education frequently classified the concept of motivation into a finer construct (Schukajlow et al., 2017; Wigfield, 1997).

Over the past decade, a vast number of studies investigated the predictive variables of student learning. Academic motivation is a crucial concept for understanding why students learn differently was largely investigated. The academic motivation was viewed as a cause of behaviors that affect student learning, such as effort investment and students' insistence on challenging assignments (Hattie & Yates, 2014a; Pintrich & Schunk, 2002). This conceptualization shows how powerful academic motivation can guide students' behavior and influence their choices. On the one hand, the effect of academic motivation appears in student learning processes. Early researchers highlighted the importance of discovering the impact of academic motivation on cognitive processes (Pintrich & De Groot, 1990). Many of them assumed that academic motivation is intimately associated with learning and influences a learner's cognitive processes (Pintrich & De Groot, 1990). Numerous empirical findings have supported this assumption. For instance, early researchers pointed out that motivation was closely related to how students use cognitive strategies to foster their cognitive engagement in learning.

Moreover, for the early research to integrate the relationship between motivation and student learning, most studies focused on particular domains or subjects, such as mathematics, English as a second language, or other science disciplines. In particular, various educational researchers have acknowledged the impact of mathematics motivation in student learning (Middleton & Spanias, 1999). Moreover, the positive predictive effect of mathematics motivation on students' academic performance was detected in nation-wide assessments such as PISA 2003 and 2004 (Kriegbaum et al., 2015). In particular, a prior study reported a significant effect of mathematics motivation on eighth-graders' mathematics performance (Singh et al., 2002). In sum, the above research revealed that academic motivation positively affected student learning, including the learning performance and learning processes.

Yet, the same class students are not equally motivated, and the motivation level keeps changing throughout the school years. Recent longitudinal research found that students' academic motivation in mathematics declines from childhood through adolescence (Frenzel et al., 2010; Frenzel et al., 2012; Hidi & Ainley, 2002). Students' curiosity and genuine interest tend to decrease over time. And the decline in adolescents' interest and willingness to learn mathematics in higher grades relate to various reasons, such as a mismatch between the learning environment and individual preferences while learning (Eccles et al., 1993). In order to generate a better understanding of individuals' academic motivation, various assessments and scales were developed to precisely evaluate this critical student characteristic (Martin, 2001).

2.3.3 Academic Self-concept

In keeping with the focus of individual learning prerequisites, as an individual learner, his reaction to himself or how he perceives "I" during the learning process is critical. This section focuses on a vital dimension of self-concept and provides an overview of the academic self-concept theory. From a student-centered perspective, McCombs and Whisler (1997) emphasized the importance of a student's ability-related beliefs and perceptions of personal competence. The students have different perceptions of themselves. One crucial individual characteristic is self-concept. When students enter the classroom, they come with a various estimation of their abilities in math, language learning, or other academic subjects. Yet, these estimations or perceptions are unobservable in classroom processes. In response to this, the current section further explores the self-concept situated in the domain of mathematics, including its stability and how it has been assessed.

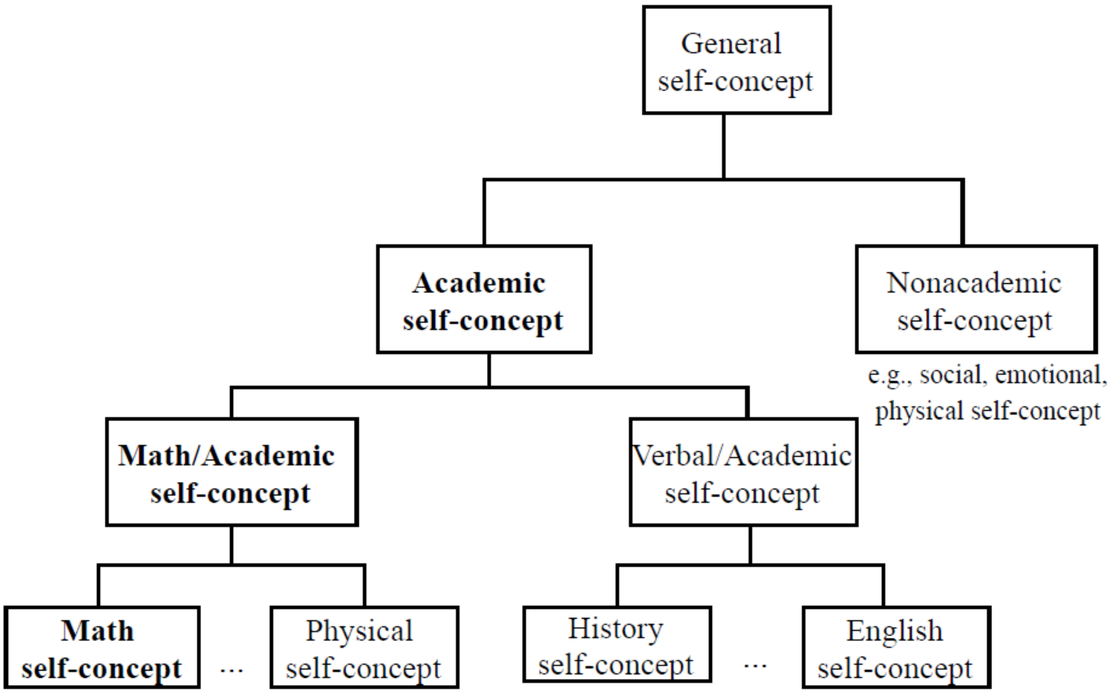
Self-concept is a critical concept in educational psychology. It has been a long time that self-concept was recognized as a critical variable that affects student learning (Wylie, 1974). In the view of many researchers in educational psychology, self-concept refers to a person's perception of ability formed through their experiences with the environment (Shavelson & Bolus, 1982). Sometimes, the two terms—self-concept and self-esteem—were used interchangeably in previous literature (Marsh, 2014). Additionally, the concept of self-concept is also highly comparable with the construct of self-efficacy (Bong & Skaalvik, 2003). However, as should be clear, the term self-concept rather than the others is used to characterize the individual learning prerequisites in the present dissertation. Since the 1980s, self-concept has evolved into a multidimensional structure that is hierarchically organized (Shavelson et al., 1976). Elaborating on this, Shavelson and Marsh noted that the general self-concept covers different educational research dimensions such as academic, social, emotional, and physical self-concept (Arens et al., 2011; Harter, 1982; Marsh et al., 1986). These dimensions are grouped into academic and nonacademic self-concept (Shavelson et al., 1976).

Specifically, academic self-concept (ASC) is defined as a person's belief and self-perception of one's academic competences and achievement (Bong & Skaalvik, 2003; Marsh, 1993). In the meantime, Eccles and her colleagues (1993) identified a similar concept called self-concept of ability (SCA). From their definition, the self-concept of ability refers to a person's evaluation of their abilities to mastery tasks. With this almost identical definition, the term self-concept of ability has been used interchangeably with academic self-concept in the existing literature. Moreover, with the development of Shavelson and Marsh's model, academic self-concept can be further divided into domain-specific facets: math and verbal self-concept (Marsh, 1990). When researchers discuss the relationship between self-concept and student learning, they rarely study it in isolation from the curriculum domains (Arens et al., 2011). Therefore, previous researchers further develop the hierarchical model by identifying higher-order factors corresponding to specific subjects (e.g., mathematics, physics, English, etc.). Unfolding the multidimensionality of academic self-concept, *math self-concept* (MSC) is conceptualized as students' self-perceptions of their mathematics learning abilities. Later, numerous studies distinguished between math self-concept and verbal self-concept and further demonstrated its domain-specificity. By now, with numerous revisions and examined by empirical studies, as illustrates in Figure 2.3, the construct of math self-concept is situated with a well-structured model (Marsh, 1990).

When narrowing self-concept down from its general structure into specific concepts, researchers also became interested in math self-concept stability. There has been a sharp increase in longitudinal research evidence that indicates that a person's academic self-concept changes with increasing age and experience (Liu et al., 2005). So far, many prior studies have identified strong relationships between academic self-concept and student learning. Later, several studies also found that the domain-specific self-concepts positively predicted domain-specific gains in mathematics (Pietsch et al., 2003), science, and language learning (Dermitzaki et al., 2009; Marsh & Craven, 2006). When the reach of academic self-concept is further limited to a more specific domain, it is closely related to students' actual learning behaviors. For instance, when students are confident in their mathematics ability and have positive self-beliefs about their math learning, they tend to solve more challenging tasks and enhance their achievement (Schunk & Pajares, 2009). Based on the hierarchical structure of self-concept and the empirical findings, it is reasonable to assume that math self-concept is situation-specific and content-specific rather than stable like a trait character. This state-like feature has attracted many researchers' interests to investigate further and assess academic self-concept.

Figure 2.3

The Hierarchical Model of Self-Concept



Note. This figure shows the revised Marsh/Shavelson Model. From "The structure of academic self-concept: The Marsh/Shavelson model," Marsh, H. W., 1990, *Journal of Educational Psychology, 82*(4), p. 623-636.

Influenced by Shavelson et al. 's (1976) model, many self-concept instruments have been developed to test students' self-perceived competencies and their affective responses in school subjects. Clearly, a thorough assessment of this unobservable student characteristic calls for the focus of multiple dimensions of measurements. Since the idea of the multidimensionality of self-concept became widely accepted, a set of Self-Description Questionnaire (SDQ) instruments was developed to assess diverse facets of self-concept, including competences in math, reading, which went beyond their perceptions of general competency (Marsh & O'Neill, 1984). Later, the measurement of academic self-concept evolved into measuring more dimensions, such as students' willingness to work hard and whether they enjoy academic subjects across the lifespan (Barbara M. Byrne, 1996; Marsh, 2014). The recent development of assessment (e.g., Academic Self-Description Questionnaire, ASDQ) refines the academic domains of self-concept to more precisely identify students' perceptions toward their competence of core academic subjects. Along with the development of measuring self-concept, the advances in the psychometric method largely enhance the understanding of this critical construct and point to promising directions for research in student learning.

2.3.4 Prior Knowledge

In addition to academic motivation and self-concept, individual differences also occur in students' prior knowledge, which is central to learning. For instance, there is a universal phenomenon in the mathematics classroom that some students acquire and digest mathematics concepts more quickly than their classmates. What makes some of these students, quite literally, learn faster? A possible reason is that students from the same classroom might not have the same level of prior mathematical knowledge, bringing variation to their learning paces. To deepen the understanding of prior knowledge, the current section describes its definition and acquisition process and why it is crucial for student learning.

In a broad sense, prior knowledge is a collective construct that reflects the skills and experiences that a person knows in advance (Dochy, 1994). In other words, people's new knowledge is built upon their preexisting knowledge. However, this early definition lacks precision and consistency, bringing about difficulties for subsequent research in education (Dochy, 1992). In particular, the vagueness of concepts negatively affected the follow-up measurement of prior knowledge, analyses of learning performance, and the interpretation of findings. Therefore, some researchers later introduced a hierarchical structure to explain prior knowledge. Dochy and Alexander (1995) developed a conceptual map to clarify different dimensions of prior knowledge further. They made distinctions between two facets of prior knowledge: domain-transcending knowledge and domain-specific knowledge. The former refers to metacognitive knowledge, which is domain-general or generic. The latter is defined as substantive knowledge about particular academic domains, such as science, mathematics, and language learning (Dochy & Alexander, 1995). Since learning requires to be more domain-specific and takes place in concrete situations, the acquisition of domain-specific prior knowledge has an enduring attraction in educational research (Gudmundsdottir et al., 1985; Shuell, 1986).

Within the focus of domain-specific or subject-specific knowledge, *prior mathematics knowledge* is used to describe a learner's existing knowledge of related mathematical concepts and procedures (Byrnes & Wasik, 1991; Kitcher, 1984; Sidney & Alibali, 2015). This subject-specific knowledge consists of two aspects. According to Brynes and Wassik (1991), for one, mathematics conceptual knowledge refers to whether the student knows the core concepts in math (i.e., know what). Instead of only emphasizing the knowledge of facts, conceptual knowledge also supports students' understanding of the interrelations of the mathematics concepts (McCormick, 1997). The other construct is procedural knowledge of math, which mainly refers to knowing the steps of solving the mathematics problems (i.e., know-how). The classification of the concept of prior knowledge provides a theoretical foundation for later studies to investigate its role and impact on student learning (Rittle-Johnson & Siegler, 1998).

There has been a long history of recognizing that a person's prior knowledge is the most crucial factor for student learning (Ausubel, 1969). How is a student's domain-specific prior knowledge related to learning? When exploring the role of prior knowledge, investigations of cognitive learning over the last two decades have confirmed the importance of prior knowledge for student learning (Dochy, 1994; Dochy et al., 2002; Tobias, 1994). Such studies have suggested that individuals' prior knowledge acts as a single factor that prepares them for future learning and significantly affects their academic achievement (Alexander et al., 1992; Dochy, 1992). That is, the prior knowledge itself significantly predicts the later acquisition of new knowledge. This positive effect of prior knowledge has been found across academic subjects and educational contexts, such as when secondary school students' better performance on a text comprehension posttest (McKeown et al., 1992; McNamara & Kintsch, 1996) was found to predict the students' final grades in mathematics in college (Hailikari et al., 2008). Even though many researchers have reported strong continuity between students' earlier academic performance in mathematics and their later performance, there has been no consensus in the existing literature on whether students who start with high levels of knowledge remain at a similar position or not. Therefore, the dynamic and changeable character of prior knowledge (Dochy, 1996; Portier & Wagemans, 1995) has attracted considerable research interest to discover the most effective approach for enhancing students' knowledge acquisition.

In addition to the positive association between prior knowledge and future learning outcomes, there has also been a small amount of research investigating the relationship between prior knowledge and other student variables, such as affective and motivational characteristics (Tobias, 1994). Prior studies found that when learners had more subject-specific knowledge at the beginning of secondary school, they were more likely to be stimulated by a specific situation and show greater learning interest in biology and physics classrooms (Alexander et al., 1995). In return, interest and motivation matter for acquiring new knowledge, which further contributes to academic achievement (Liu et al., 2012). Regarding the student characteristics in learning, numerous factors have been explored and confirmed the importance of teaching and learning. Based on the understanding of the crucial role of prior knowledge in student learning, educators and researchers devote vast effort to enhance it. Promoting students' cognitive ability and learning performance is feasible only when individuals use learning opportunities effectively. To achieve effective learning, it requires students to actively involve and engage in the learning processes.

Since the prior mathematics knowledge plays a crucial role in student learning, it has been a long time that educators and researchers devote to assessing individual students' prior mathematics knowledge to evaluate their mathematics competences. Over the past decades, numerous international large-scale assessments were administered to test school-aged students' mathematics knowledge, such as mathematical literacy (Liu & Wilson, 2009) and mathematics skills (Schleicher, 1999). For instance, a vast amount of students' mathematics performance was measured and compared by OECD's Program for International Student Assessment (PISA) as well as by IEA's (International Association for the Evaluation of Educational Achievement) Trends in International Mathematics and Science Studies (TIMSS) across countries (Mullis et al., 2004; Wu, 2006). Comparing and analyzing the development of students' mathematics competence across educational systems and across time provides researchers useful clues to renew the original approach of developing students' mathematical knowledge (Resnick, 1989).

In short, this section focused on three individual learning prerequisites by addressing several critical issues, such as the definitions identified in the early learning theories or models, their relationships with student learning processes, and the assessments in previous literature. The critical individual learning prerequisites are more than these three. Nevertheless, a comprehensive elaboration of all the student characteristics is beyond the scope of the present chapter. Hence, building on the current understanding of students' academic motivation, self-concept, and prior knowledge, the next section pays attention to how to engage the different students with unique characteristics actively in the learning processes.

2.4 Student Level: Student Involvement in Learning Processes

"Education is not the filling of a pail, but the lighting of a fire."

—Yeats, W. B.

As described earlier in this chapter, individual learning prerequisites such as prior knowledge, academic motivation, and academic self-concept are crucial student factors that affect learning processes in the classrooms (Deci & Ryan, 2010; Marsh & Martin, 2011). However, these motivational and cognitive prerequisites alone are not sufficient to guarantee that students will use the opportunities they are given effectively. The students also need to be cognitively and motivationally engaged in learning activities. From the constructivists' perspectives, the nature of learning is an active process that happened within an individual. This underlying idea is also reflected in the supply-use model, which insisted on how students perceive and respond to teaching are varying at an individual level. To deepen the understanding of individual learning processes and relevant learning activities, the current section aims to unfold the student learning process of the supply-use model, especially discussing how to engage students in active learning and why this matter for using the opportunities effectively.

2.4.1 Student Learning Process

According to the supply-use model, the student learning process, as a component in the complex interactive framework, plays a transitional and crucial role between the teaching process and learning outcome (Helmke & Schrader, 2013). In other words, after students received any information or knowledge from instruction (i.e., the input end of the box), the process starts to enter a mediating mechanism where we have a limited understanding of the interrelated actions. When something observable again, it is the output end of learning. Depending on whether learners are actively involved in the learning process, it can positively or negatively affect the learning outcomes. Thus, it is crucial to understand this indispensable link before finding an effective approach to enhance it from my point of view. However, the concept of the student learning process is not concrete enough to describe the characteristic of the involvement process, especially stressing the bright side of student responses and classroom activities. In response to these issues, a more specific focus and relevant theories about the active facet of the student learning process are required.

2.4.2 Defining Active Learning

From the constructivists' perspectives, learning is an active process of acquiring knowledge and understanding new ideas (Lachman, 1997; Von Glasersfeld, 2002). They stressed that learners spontaneously acquire knowledge and develop their competence through engagement. In this sense, learning should not be a passive process that does replication and reproduction of knowledge. Based on this argument, previous researchers criticized that traditional education treated learners as passive receivers of knowledge from teachers regardless of individuals' characteristics and needs in learning (Dewey, 1933). More educators and researchers rejected traditional education across the past decades and explicitly promoted active learning in academic settings (Bonwell & Eison, 1991). They insisted that learning is a continual process through which students actively construct their knowledge and acquire new skills in a self-directed way (De Corte, 2004). Besides, constructivists have also argued that knowledge acquisition is more likely to succeed when individuals engage in an active learning process. Meaningful learning occurs when the learner actively involves and engages in the information acquisition process, which is later aggregated into existing knowledge (Fiorella & Mayer, 2015). Therefore, educators are encouraged to move from a passive approach to encouraging an active learning process. Numerous educational researchers have attempted to provide a clear description of the nature of active learning (Johnson & Johnson, 2008; Tong, 2001). They claimed that constructive activity appears in two aspects: physical actions and mental activities in learning. In academic settings, active learning is a vital element of classroom practices as it helps students engage in higher-order thinking tasks (Caceffo & Azevedo, 2014). Compared with physical action, the mental aspect of active learning is unobservable and plays a more crucial role in engaging cognitive learning. The following discussion about active learning is to focus on the learning process that happens in mind.

The concept of active learning refers to a process that learners take the initiative to make sense of new knowledge or novel ideas by connecting their prior information in a cognitive framework (Bonwell & Eison, 1991). During this process, learners are active participants who use different cognitive processes to develop knowledge and skills (Cohn, 2010; Mayer, 2005). An active learner acquires knowledge and develops an understanding of the world by raising their needs and receiving responses. But how can education turn the student learning from a passive mode to an active process? When we disentangle the general educational goal into smaller objectives, it composes of six dimensions: remembering, understanding, apply, analyze, evaluate, and create (Bloom et al., 1956). From memorization to creation, the six types of cognitive learning objectives are part of an escalating process. During this process, the difference between passive learning and active learning becomes larger. While achieving the above objectives, active learners are self-directed and aware of learning needs (Wright & Shade, 2018). To go beyond memorizing and accumulating, the active learner would develop curiosity and interest in the knowledge transfer process (Cardullo et al., 2015). When students are attending different types of learning activities, the most persistent issue that tends to disrupt active learning is disengagement (Bergdahl et al., 2020), which can come from either the motivational or cognitive perspective. Therefore, it is essential to get students to become motivationally engaged to facilitate the active learning process. In other words, it provides a hint of turning a passive learner into an active one. The active learning in this dissertation is not limited to cognitive engagement but is considered from a motivational perspective.

2.4.3 Linking Student Involvement to Active Learning

As described earlier, active learning has been conceptualized as a process that requires students to involve both *cognitively* and *motivationally* in learning activities (Bonwell & Eison, 1991; Corno & Mandinach, 1983; Skinner et al., 2009). In a similar vein, recent researchers have identified three aspects of involvement in student learning processes: affective-emotional engagement, cognitive engagement, and behavioral engagement (Skinner & Pitzer, 2012). At this point, the terms of involvement and engagement are frequently used interchangeably in the previous literature. The fact is that they do largely overlap in terms of their definitions and compositions. However, to have a clearer view of the student factors contributing to learning, it is vital to avoid the jingle-jangle fallacies in learning theories.

Generally, the concept of student involvement refers to the physical and psychological input that a learner invests along a continuum in the learning experience (Astin, 1999). Student engagement is defined as the extent to which a learner is actively involved in a learning activity (Finn, 1993; Finn & Zimmer, 2012). Similar to involvement, student engagement is identified as a multifaceted construct that comprises of three dimensions (Fredricks et al., 2004). According to the given definition, it is a little disappointed that involvement and engagement refer to a similar learning phenomenon. However, it does not hinder the progress from opening the “black box” of students’ active learning processes. But what are the critical pathways that support students in becoming active learners? Using student involvement as the standpoint, educational researchers continuously explore the learning processes that explain how teaching and instruction are transferred into different responses and development. To unfold this mediating mechanism, it is vital to take an in-depth look at student involvement composition.

Early research suggested that students can be motivationally or cognitively involved in the learning process (Corno & Mandinach, 1983). Thus, a possible way to promote active learning process is facilitating student involvement. The involvement process could take place on both the motivational and cognitive levels. First, from a non-cognitive perspective, when teachers try hard to involve their students, they sometimes struggle to trigger individuals' curiosity and interest in learning activities. That is, interest is an indicator of whether a person is motivationally involved. Second, from a cognitive perspective, Chi and Wylie (2014) argued that the cognitively engaged student shows a great deal of involvement in learning activities. Therefore, active learning can be achieved through two pathways: (a) by creating situations in which students' interests are triggered (Brown & Ford, 2002) or (b) by cognitively engaging students in learning activities (Chi & Wylie, 2014). In the present chapter, the suggestions for implementing active learning are provided in two directions. The following paragraphs discuss in greater detail how teachers can get students involved in the active learning process.

Situational Interest. In general, when students experienced energized, excited, and emotionally involved, they are interested in the subject matter (Harp & Mayer, 1997). Besides, the increase in student involvement that has been discussed from an emotional or motivational perspective makes attention shifts to the extent of what students are interested in learning (Hidi, 1990). In classroom processes, a lack of interest is a critical issue that prevents students from becoming engaged in the school learning context (Frenzel et al., 2010). Stimulating students' interest uses the motivational pathway to involve them in active learning. To a certain extent, the attribute of emotional feeling (e.g., being happy, liking a topic, being interested in a topic) overlaps a great deal with interest (e.g., intrinsic enjoyment of learning). Meantime, compared with the vague definitions that have been used in motivational involvement, the theory of interest has provided a more elaborate definition of interest. Hence, the theoretical work on interest aids the understanding of students' non-cognitive involvement.

Generally speaking, interest refers to a person's psychological state when interacting with environments and other people. Additionally, motivational researchers have suggested that interest is multifaceted. For instance, Krapp (1989) offered a more refined distinction between personal interest and situational interest and highlighted the necessity for this distinction for education research. In his model, personal interest (PI) was identified as a student's enduring desire to be involved in learning tasks or activities. Unlike PI, situational interest (SI) simply refers to a temporary psychological state of interest in a task or learning activity (Hidi et al., 1992). Students acquire SI while participating in an environmental setting, and this short-term action is changeable (Krapp, 2002). Based on this nature, the students' SI is elicited by aspects of a situation when they participate in a context (Mitchell, 1993). For instance, some students may be interested in numbers before entering a mathematics classroom (PI). By contrast, some other students probably acquire an interest in the Pythagorean Theorem after successfully calculating the height of an Egyptian pyramid (SI). The novelty of the topic may have aroused these students' interest.

Based on the definition, the state-like character of SI makes it possible for students to develop SI (Bailey et al., 2014; Hidi & Renninger, 2006). Thus, Hidi and Renninger suggested a specific approach for eliciting students' SI from two facets: First, a triggering condition must be created for students. This condition is the *catch* facet of SI, emphasizing the importance of creating an appropriate environmental setting. The appropriate situation makes learners generate a positive perception of a concept or a course. After capturing students' interest, the second facet of SI involves successfully *holding* students' interest. This holding facet is strongly related to overall SI and plays a vital role in maintaining student interest across time. More specifically, individuals who perceive that specific learning tasks are meaningful for their future goals are more likely to continue to exhibit situational interest and remain involved over time. Once the catch and hold facets of interest are fulfilled, students are significantly more likely to remain emotionally and motivationally engaged in learning new knowledge. In sum, emotional engagement can be achieved by stimulating and maintaining students' situational interest in the learning context.

As a critical student characteristic during the interaction with the learning task, educational researchers are interested in assessing whether students perceive the instruction as interesting via different approaches (Chen & Darst, 2001; Mazer, 2012). For example, in previous literature, students' situational interest was viewed to be linked with different sources. Thus, situational interest was measured based on an underlying multicomponent model. To operationalize the assessment, researchers designed and conducted the Perceived Interest Questionnaire with a selection of items (e.g., "I thought the story was very interest.") to measure the overall concept of situational interest (Schraw et al., 1995). Furthermore, with the development of the specificity of the concept, more recent studies insisted that student interest in teaching and learning were considered as a multidimensional construct that assessed via self-report interest scales (Mazer, 2013). In addition to the self-report assessment format, observational methods were also used as a complement to better understand the interest and engagement (Fredricks & McColskey, 2012). During the observation, the resources (e.g., novelty or challenge) that trigger or catch students' interest in particular content were recorded and analyzed in experimental settings (Renninger & Bachrach, 2015). Taking together, the use of multiple approaches in assessing situational interest provides a clearer insight into the nature of student learning processes and those critical factors related to student characteristics.

Cognitive Engagement. The second pathway of involving students in learning can be achieved by enhancing their cognitive engagement. As discussed before, engagement is defined as students' active involvement and commitment to learning (Christenson et al., 2008). The concepts of involvement and engagement are, most of the time, used interchangeably across context. In a review of student engagement literature, researchers recently proposed a tripartite conceptualization of engagement composed of three dimensions: emotional engagement, cognitive engagement, and behavioral engagement (Appleton et al., 2006; Azevedo & Sherin, 2012; Fredricks et al., 2004). According to Finn (1989), behavior engagement reflects observable, action-oriented involvement (e.g., participating in learning tasks, paying attention in class), and emotional engagement refers to students' affective reactions to school, teachers, and academic work (e.g., interest, boredom). Unlike the previous facets of engagement, cognitive engagement was defined as a person's mental investment in learning (Connell & Wellborn, 1991; Newmann et al., 1992). These student engagement dimensions provide a different explanation of student learning distinguished from the motivational theories. Besides, the structure of student engagement provides a framework to guide the systematics understanding of learning processes.

As indicated previously, cognitive engagement refers to a student's active mental involvement in learning tasks, such as that person's willingness to invest and exert effort to understand complex ideas or complete a difficult task (Fredricks et al., 2004). Additionally, cognitive engagement also reflects an individual's interaction with the external environment, which means that cognitive engagement cannot be isolated from the context (Russell et al., 2005). When students are cognitively engaged in their learning tasks or activities, they attempt to construct a coherent cognitive system that integrates the relevant components of new information into the existing ones. They can then learn or achieve more than those who are cognitively disengaged in academic work. This importance of student engagement is widely recognized by researchers (Skinner & Pitzer, 2012).

Building on the critical role of cognitive engagement, the question that arises is: How can cognitive engagement be evaluated? Educational researchers have invested effort in measuring cognitive engagement (Fredricks et al., 2011). Several recent reviews have summarized the instruments that used to assess student engagement (Fredricks & McColskey, 2012). Based on the research goals, the vast variety of measurements were administered and selected to offer a comprehensive understanding of student learning processes. Some of them focus on particular age-group and educational context such as secondary school student (Appleton et al., 2006); or using multiple methods such as student self-report scales (Greene, 2015); or situated in particular subject context such as mathematics (Kong et al., 2003). With the further development of validated instruments, it would be possible for researchers to gauge student engagement and better identify how the students are involved in learning. Using multiple methods to assess the phenomenon of student engagement, this student factor was discovered to be a significant predictor of successful teaching and learning, and students who were actively engaged tended to understand more while they learned (Carini et al., 2006; Park, 2003). More specifically, student engagement was strongly associated with the class participation (Richter & Tjosvold, 1980) and graduation rate in high schools (Finn, 1993). These findings pointed out the positive impact of engagement, which plays a crucial role in student learning. As the connection between engagement and active learning increases, recent studies have attempted to investigate the effect of student engagement on individual learning.

2.4.4 Relationship Between Learning Prerequisites and Student Involvement

As described earlier, the constructivists claimed that student learning is self-directed and active processes. Based on this underlying argument, many recent learning theories describe student learning as a knowledge and skill acquisition process. Nevertheless, these theories do not specify the interaction between individual learning prerequisites and students' use of the opportunity to learn (Cueto et al., 2006; Klieme et al., 2009). Getting students involved is a function of numerous interrelated variables and primarily depends on the individual-level factors. Regarding this complicated process, many educators have long acknowledged the importance of student characteristics such as motivation, self-concept (Denissen et al., 2007; Marsh et al., 2006), and prior knowledge (Tobias, 1994) in learning. The current theoretical framework also highlighted the crucial roles of individual students' motivational and cognitive characteristics of their learning processes. According to the model, it suggested that student characteristics directly impact learning outcomes (Helmke, 2001; Rukanuddin et al., 2016). Moreover, such characteristics also act as the learning prerequisites influence (a) how students perceive the instruction they receive and (b) how they use their learning opportunities accordingly (Seidel, 2006). Given these relationships, it is reasonable to assume that student involvement also has some prerequisites to reach. However, teachers and educators still lack a clear view of how these individual characteristics contribute to student involvement while they learn.

As noted previously, the construct of situational interest and cognitive engagement are identified as the two essential factors in student involvement. Both constructs are dynamic and can be promoted during the interaction between a learner and a classroom learning context (Fredericks et al., 2004). Since individual learning prerequisites cover numerous student factors, a thorough discussion on student involvement is difficult to accomplish in this chapter. Therefore, the current section outlines the effect of a few cognitive and non-cognitive characteristics on student involvement in learning processes. The recent educational researcher also claimed that student engagement is essential for understanding and explaining students' attitudes and motivations (Lee, 2014). In short, the existing studies tend to argue that if you plan to involve the students actively, their differences in learning characteristics should be taken into consideration. But these previous findings mostly concluded from the traditional classroom settings. More empirical evidence is needed if the learning environment is changed.

To sum up briefly, the current section outlined why active state matters for student learning. The importance of active involvement and its relevant components were discussed. During the instruction, teachers devote to continuously trigger the students’ curiosity, facilitate their interest, and make them actively engaged in learning. To activate the students’ prior knowledge, interest, and motivation, teaching should accommodate students’ individual learning prerequisites and needs. When the teaching process is dynamic and flexible, it encourages better interaction between students and teachers. Therefore, the concept of adaptive teaching is taken into consideration in the next section.

2.5 Interaction Between the Supply and Use: Adaptive Teaching

"Every student can succeed when taught in a way that builds on strengths and compensates for weaknesses."

—Robert J. Sternberg

In Section 2.3, we learned that individual differences appear in students' motivational and cognitive learning prerequisites that lead to diverse perceptions and learning ways. In Section 2.4, we knew that only when the students are actively involved in the learning processes can they achieve better learning. In the current section, I would like to discuss a process-oriented approach considering individual students' prerequisites and extent of involvement as the priority. Among the reciprocal relationship between teaching and learning, the central goal of instruction is to provide equal learning opportunities to facilitate all students' learning. These equal opportunities cannot be achieved without accommodating the differences in individual learning prerequisites. In turn, students are likely to benefit from the adjustable content, adaptive assessment, and personalized feedback, all of which are suitable for matching their characteristics and meeting their learning needs.

Imagine a classroom scenario where a teacher is giving a mathematics lesson to twenty students; some learn quickly, yet others may require more elaborative explanation and guidance. In the meantime, each of these students exhibits a unique combination of motivational and cognitive characteristics. Therefore, when a teacher wants to offer optimal opportunities to students, they should first recognize the heterogeneity of student characteristics in learning and then take them into account (Park & Lee, 2004). It means that the teacher needs to teach individuals within classrooms instead of teaching a class as a whole (Corno, 2008). When individual learning prerequisites are treated as the starting point of teaching, the instruction should be different and optimal for students' learning needs (Fyfe et al., 2012). Second, when the teaching process is adaptive, it accommodates the differences present in students' emotional, motivational, and cognitive characteristics. With the adaptive character, the supply of teaching is superior to one-size-fits-all instruction (Cooper, 2009; Park & Lee, 2004). As noted above, it generates a dynamic and reciprocal relationship between the supply and the use of learning opportunities.

In a similar vein, the reciprocal relationship between teaching and learning also stresses the dynamic interaction. For one, due to different individual learning prerequisites, the students' learning opportunities do not affect all students in the same way. Second, in turn, students' learning prerequisites influence the alternatives offered by the instruction. Therefore, this reciprocal relationship highlights the importance of a match between the supply and use of learning opportunities. To strengthen this relationship, many constructivists believe that making instruction personal to students' interests and needs will help them reach a more in-depth understanding of learning. Central to these ideas is the requirement that teaching should be adaptive for each student. Based on these requirements, a clear description and classification of the concept of adaptation are needed.

In a generic sense, the concept of adaptation refers to any adjustments or modifications made for individual students based on their characteristics and requirements in learning. Educational researchers have concerned with adapting their school teaching to individual differences for an extended period. Previous studies have suggested different ways to promote individual learning successfully. Two main trends could capture these ways: First, these studies focused on teacher characteristics (e.g., teachers' beliefs and knowledge associated with adaptive teaching) and highlighted the need for teachers' adaptive teaching competencies (Brühwiler & Blatchford, 2011; Parsons et al., 2018). The studies that reflected this trend emphasized how important it is for teachers to develop their professional knowledge and spontaneously respond to learners' diverse learning abilities, motivation, and needs (Allen et al., 2016; Tomlinson, 2000; Wang et al., 1990). The second major trend focused on using alternative teaching processes to provide appropriate learning opportunities to students. The latter approach is discussed in the following section, with a closer look at enhancing the adaptation by modifying instructional activities. Moreover, such a possible instructional adaptation can be achieved by adjusting the curriculum, altering the tasks' difficulty, and providing personal feedback.

2.5.1 Definition of Adaptive Teaching

The focus on effective teaching and learning has taken on board the concept of adaptive teaching. The idea of adaptive teaching sounds familiar, and the meaning seems commonly understood. However, the concept of adaptive teaching has not been defined precisely in the literature. Vastly different conceptualizations can bring confusion and misunderstandings of this classroom phenomenon. In the discussion of adaptation in the classroom, the main confusion comes from the definition. In the variety of conceptualizations, there is no consensus on what adaptive teaching is. In the early learning theory, adaptive teaching was introduced to meet the needs of individual differences (Corno & Snow, 1986). Later, the conception of this phenomenon was more concretely revised. According to Radi and Corno (1997), adaptive teaching was conceptualized as a series of instructional activities that have been adjusted. Teachers can demonstrate teaching techniques and present material in a way that allows them to achieve an intended learning outcome. However, this early definition still did not clearly define the relevant alternative classroom activities associated with adaptive teaching. Moreover, from my perspective, adaptive teaching should go beyond the concrete steps and involve a broader scope of teaching processes.

In the present dissertation, adaptive teaching refers to an interactive educational approach that provides a variety of suitable opportunities to satisfy individual students' learning needs while helping them develop knowledge and acquire skills (Park & Lee, 2004; Wang, 2001). More specifically, adaptive teaching should not be limited in its delivery of appropriate learning content, but rather, should also provide adaptive assessment, personal feedback, and more alternatives for learning activities. Furthermore, it is generally accepted that various approaches and alternative instructional strategies are ultimately to provide equal learning opportunities for all students.

The second source of confusion is the use of terminology that leads to jingle-jangle fallacies. For a considerable amount of the literature on adaptive teaching, scholars have used different terms to address this classroom phenomenon, such as adaptive instruction (Parsons et al., 2018; Snow, 1986; Wang, 2001), adaptive teaching (Corno, 2008), adaptive education (Glaser, 1977), personalized instruction (Keefe & Jenkins, 2008), personalized learning environment (Kim, 2012), individualized instruction (Cooley & Glaser, 1969), differentiating instruction (Kauchak & Eggen, 2012), and differentiated instruction (Prast et al., 2018; Smit & Humpert, 2012). Even though teaching and instruction are used interchangeably in many educational contexts, these two concepts are different.

Generally, an instruction refers to a series of actions to demonstrate, present, and model to reach an intended learning outcome. Nevertheless, teaching provides a broader scope, instead of simply following the concrete steps. Teaching is seen as an interaction among teachers, students, instructional methods, learning content, and materials in classroom. This interactive process involves guidance, feedback, as well as providing learners opportunities to experience and apply their knowledge (Ridley, 2007). Based on the above clarification, compared with adaptive instruction, adaptive teaching is a more proper term to describe the phenomenon that involving broader components in the teaching processes. Therefore, adaptive teaching is the term that will be used in the present dissertation and keep consistent throughout the discussion. Even though the concept of adaptive teaching is well-defined, the knowledge on this topic is still fragmented and full of uncertainty. An effective implementation of adaptive teaching cannot serve its purpose without linking it to concrete instructional components and classroom activities. Therefore, progress in a systematic understanding of which teaching strategies that have been closely related to adaptive teaching is still needed. The next section elaborates on three aspects to make adaptive teaching possible in teaching practices.

2.5.2 The Importance and Barriers of Implementing Adaptive Teaching

The need for adaptive teaching is grounded in two assumptions. First, students have different characteristics and do not learn in the same way. Second, students' motivations and abilities to learn can be enhanced by the teaching process (Glaser, 1977). When concerning the approach applied to compensate for individual weaknesses, the importance of adaptive teaching has been widely recognized (Corno & Snow, 1986). When considering the effects of adaptive teaching, Hattie (2009) claimed that it is associated with instructional quality and successful learning outcomes. Recent studies have proposed that adaptive teaching can provide subsequent learning opportunities to more advanced or weaker students to match their learning needs (Wang, 2001). When provided with appropriate learning opportunities, students with diverse prior knowledge can learn at their own pace. The adaptive learning opportunities transfer students' weaknesses into strengths to become more competent learners (Corno, 2008; Dumont, 2018).

Furthermore, the importance of adaptive teaching also appears when it incorporates diverse teaching strategies and technologies to deal with student heterogeneity (Randi & Corno, 2005). The critical role of adaptive teaching also appears to be a promising pedagogical approach to reaching this goal (Dumont, 2018). The next concern is how to tailor one's teaching in classroom practices. To enhance student learning, researchers have started to discover different educational approaches and instructional technologies to accommodate the individual characteristics and developmental levels in the classrooms.

Despite realizing the crucial role of adaptive teaching, the broad agreement on the importance does not solve the mismatch between the supply and use of learning opportunities during the instructions. When coming to classroom practices, the obstacles of adaptive teaching could be the considerable strain on teachers' time and skills, or the potential impairment of low-achieving students (Pelgrum, 2001). Teachers still apply an identical lecture to the whole class without concerning their background and learning prerequisites. At this point, it was critically not easy to implement adaptive teaching in the classroom processes. Many teaching methods and strategies have been discussed to achieve an equal opportunity in a heterogeneous classroom (Lazenby, 2016). Nevertheless, there are numerous obstacles to educational research and classroom practice to implement adaptive teaching. The absence of adaptive teaching in classrooms is due to numerous reasons. For one, when thinking about situating the adaptive teaching into quantitative research, how to quantify and assess adaptive teaching remains unclear (Dumont, 2018). Moreover, the effective evaluation or measurement of adaptive teaching is full of uncertainty. In previous qualitative research, the researcher had attempted to summarize critical instructional activities through analyzing or coding teachers' lesson plans. In other words, the implementation of adaptive teaching cannot be integrated into a standardized teaching routine. Therefore, it brings the fact that although a heterogeneous classroom environment highly requires adaptive teaching to deal with individual difference, the actual educational practice remained fixed and the appearance of adaptive teaching appear less frequently than it expected (Snow, 1986; Warwas et al., 2011).

During an instruction, once teachers recognize the differences in students' learning interest, motivation, self-concepts, and cognitive abilities, to deal with the heterogeneity becomes a starting point of their teaching (Corno & Snow, 1986; Prast et al., 2018; van den Berg et al., 2000). With no additional assistance, the implementation of adaptive teaching is full of challenges for the teacher, especially the inexperienced teachers (Westwood, 2018). Despite problems, making teaching adaptive has an enduring attraction, and the concept of adaptive teaching emphasis the intent to support a sound foundation for the student.

To provide the appropriate learning opportunities to students, teachers invest effort into deciding which aspects of their teaching to adapt proactively (e.g., level of difficulty, learning materials, methods, and environment); how to adapt them (e.g., through elaborative explanation, diagnosis, and feedback); and how they will use what they adapt (e.g., technology) (Allen et al., 2013; Shulman, 1987). These examples of providing appropriate learning opportunities give some clues of implementing. Additionally, a previous study identified the critical characteristics for effective adaptation (Wang, 2001). For instance, adaptation appears when teachers monitor student learning process throughout the class time. However, there is no systematic framework that characterizes some classroom activities that can be identified as adaptive teaching. With the limited knowledge in the relationship between adaptive teaching and concrete instructional components, the implementation of adaptive teaching in classrooms is full of obstacles. Therefore, recent educational researchers attempt to categorize some teaching components and link them with the idea of adaptation.

2.5.3 *Adaptive Teaching: Three Facets*

Consistent with the nature of teaching, adaptive teaching is complicated and comprises different compositions to fulfill the specific purposes for education. Three main approaches are essential for achieving adaptive teaching: (a) adaptive content, (b) adaptive assessment, and (c) adaptive feedback. These facets constitute a multifaceted adaptive teaching process. In other words, the composition of adaptive teaching appears in three parts. The following discussion attempts to identify a structure that helps to bridge the idea of adaptation to particular teaching components.

Adaptive Content. An underlying idea of adaptive content is to provide scaffolding to students who need individual support during instruction. In this sense, the exploration of adaptive teaching requires a thorough understanding of scaffolding in student learning. In academic settings, teachers prepare and deliver concepts and knowledge of particular subjects to an individual student during the instructions. Instead of discussing the specific content that transforms from teachers to students, the concept of adaptive teaching represents the nature of scaffolding (Hammond & Gibbons, 2005).

When teachers attempt to design the adaptive content, the basic consideration is individual learning prerequisites (Wang, 2001). The content should be consistent with the differences in individual students' prior knowledge and other learning characteristics. For instance, in a mathematics class, every student may have a different understanding of a particular topic (e.g., algebra, geometry) or smaller theme (e.g., measurement, fractions). As a result, the students acquire a different knowledge that further influences their future study (Recht & Leslie, 1988). A crucial role for teachers to scaffold student learning is to respond to the variance in student characteristics. When students have difficulties in problem-solving, they require further explanation or more support to develop subject-specific skills. A primary value of adaptive teaching is to deliver the appropriate content that scaffolds as many students as possible within a class.

But how to scaffold the students with different individual learning prerequisites? The instructional theory and research of adaptive instructional designs provided some useful clues and values on the classroom implementation of adaptive content (Schwartz et al., 1999). According to Schwatz et al., the key criteria for helping students explore and learn at their pace is to provide adaptive instructional materials. The resources that teachers provided in class should cover the relevant subject matter and principles consistent with the individual students' prior knowledge and levels of understanding. When the information and experiences that teachers provide to the class is modified according to individuals' needs, what appears next is to assess and evaluate the effect of the teaching processes. At the assessment facet, adaptation also plays a critical role in providing the individuals the appropriate opportunities to learn.

Adaptive Assessment. The understanding of adaptive assessment requires a quick run through the concept of assessment. In a generic sense, when teachers want to judge students' level of understanding and learning performance, the evaluation and assessment are needed. Based on the preexisted criteria and standards, the assessment provides teachers with an overview of students' performance, including their strengths and weaknesses. Assessment of student learning consists of two approaches: summative and formative assessment (Bloom, 1971; Taras, 2005). These two kinds of assessments have particular roles, concerns, and usefulness in classroom practices (Dixson & Worrell, 2016; Harlen & James, 1997). In academic settings, the summative assessment frequently takes place at the end of the study period that aims to provide judgment on how much a student learns (Biggs, 1998; Taras, 2009); whereas, the formative assessment focuses on the information of how to improve student learning and happen across the learning processes. Based on the above distinction, the implementation of adaptive assessment or adaptive testing may also have two alternatives. Adaptive assessment shares the common functions of regular assessment but can uniquely address the individual differences during the evaluation processes. During the classroom assessment practices, some testing is not aligned to the students' prior knowledge (Crooks, 1988). In order to solve this isolation, adaptive assessment has an enduring attraction to educators and researchers.

Adaptive assessment is defined as a dynamic assessment process without fixed questions or items. In most of the prior literature, the concept of adaptive assessment usually appears along with the use of ICT (Harlen & Crick, 2003), computers (Krouska et al., 2018), or technological system (Gouli et al., 2001). The most likely explanation of this phenomenon is the distinctive potential of technology in adapting evaluation possible. With the assistance of computers, adaptive assessment can provide a new estimation of students' performance based on their previous responses. Consequently, the difficulty and content of the subsequent questions are adapted from the new estimation (van der Linden & Glas, 2010) . Therefore, it is obvious that the adaptive assessment is nearly inapplicable without the help of technology. Concerning the diversity in students' prior knowledge, it is crucial to implement the adaptive assessment in the classroom environment. More discussion about the integration of technology in the adaptive assessment will be discussed later in this chapter.

Coming after the adaptive and formative assessment, feedback is another powerful approach implemented in instructional activities. In some previous literature, the idea of assessment is particularly overlapped with the concept of feedback (Taras, 2005). Similar to assessment, feedback can be accommodated to individual performance and learning needs.

Adaptive Feedback. As a critical component of instructional activities, the implementation of adaptive teaching can also start from providing adaptive feedback. Before the relationship between adaptive feedback and student learning can be clearly understood, it is helpful to briefly review the general concept of feedback. In a generic sense, feedback refers to the information provided by a teacher regarding a student's understanding or learning performance (Hattie & Timperley, 2007). Shute (2008) claimed that depending on educational purposes, feedback could either simply indicate an error (i.e., corrective feedback) or provide elaborative information to modify student learning (i.e., formative feedback). Many previous studies claimed feedback as one of the most powerful predictors of student learning (Hattie, 2009). With effective feedback, it gives the students the opportunities to see where they are in an ongoing learning sequence. Through providing appropriate learning opportunities such as elaborative explanation during the instruction, feedback can scaffold individual learning (Lachner et al., 2017). Recent research also raises an intensive discussion on how to provide effective feedback (Hattie & Timperley, 2007). After students respond to their teacher's question, what do they expect for the next? They may want to get back any information regarding their answer or performance, which is vital to make meaning out of what they have learned.

Numerous strategies and approaches have been used to provide effective feedback. Hattie and Timperley (2007) pointed out the common formats can be written (e.g., mid-term evaluation, the correctness of homework) and oral feedback (e.g., encouragement, responses) from teachers, peers, and parents. These traditional approaches, on the one hand, was identified as the most effective factor to reveal the mismatch between what a student is understood and what does he or she need to understand. However, the conventional format of feedback also has drawback. For one, when feedback contains more correctional information or simply summarizes the previous learning performance, as a result, it only conveys the correctness without any elaboration explanation to students (Kulhavy, 1977). Since the students are barely told right or wrong, the feedback does not contribute to the advances learning.

In addition to the content of feedback, another limitation of the traditional type of feedback is about the timing (Attali & van der Kleij, 2017; Butler et al., 2007; Kulik & Kulik, 1988). For instance, after students provide class responses, they frequently received the delay feedback on their learning performance. Kulik and Kulik (1988) also pointed out the longer interval (e.g., range from immediate to seven days) between performance and feedback produces different learning outcomes. Thus, numerous empirical studies and reviews highlighted the benefits of timely feedback. Nevertheless, if giving no assistance for competence, teachers face vast difficulty in the implementation of adaptive feedback (Sales, 1993). In the past decades, educational researchers believe that more appropriate teaching methods are emerging (Smits et al., 2008). More alternatives that appear to overcome the difficulties of providing feedback such as computer-based feedback will be described later in this chapter.

As noted earlier, the implementation of adaptive teaching still exists. Despite the difficulty, it is still necessary to discover efficient teaching practices for accommodating the diversity of the class. Although facing these challenges and drawbacks, as an overarching concept, adaptive teaching can incorporate with different teaching methods and technologies to deal with the student heterogeneity (Randi & Corno, 2005). Taking this advantage as an opportunity, some researchers suggested integrating technology as an innovative method to assist teaching and accommodate student heterogeneity within a class (Federico, 1999; Murphy & Davidson, 1991). In pursuit of adaptive teaching, technology may have numerous distinctive potentials and functions, such as providing individualized interfaces, personalized context, interactive feedback, as well as timely access to information. All these are not feasible in traditional teaching. More discussion of the integration of technology in adaptive teaching would be presented later.

2.6 Interplay Between ICT-Based Instruction and Student Learning

This section links the use of technology with the teaching and learning factors outlined in the previous section. As described earlier in the technology-based instruction (2.2), it is reasonable to assume that future classroom scenarios will be full of technology. Standing in front of a new classroom environment, educators should base their teaching and instruction on a new understanding of the nature of student learning. When more technologies and tools are introduced and utilized in classrooms, what impacts student learning? The integration of technology for educational purposes may change traditional conceptions and generate new student learning assumptions. Although early researchers conducted many meta-analyses about the use of educational technology, they systematically examined the impact of educational technology on student outcomes (Kulik, 1994). Additionally, many of the studies even narrowed down the effects of the specific type of technology (e.g., computer programming; Liao & Bright, 1991).

The current version of the supply-use model has covered most of the crucial factors associated with the active learning process; however, it did not formally explain the interconnection between the use of technology and student learning processes. That is, the effect of ICT-based instruction and student learning remains unclear. The existing learning theory is not sufficient for understanding the interplay between educational technology and student learning. Therefore, the following sections begin discussing whether ICT-based instruction compensates for individual learning. The positive effect of ICT-based instruction on student learning is probably due to the potentials of technology to work with individual differences. Therefore, the next section explores the potential of ICT-based instruction and how it contributes to adaptive teaching. Later, with the potential to acknowledge individual differences within a single class, the effect of ICT-based instruction on students' active learning processes is discussed.

2.6.1 Compensate for Individual Differences through Technology Integration

In education, variability in student abilities appears not only at the school level but also at the classroom level. Imagine a scenario in which a math teacher is facing a class of seventh graders. Following the lesson plan, the teacher is supposed to cover the Pythagorean Theorem today. But the fact is these students have a different level of acceptance to the previous knowledge. For instance, some students have not yet mastered the topic of calculating squares (e.g., $5^2 = 25$), so that they have difficulty building on prior knowledge to understand the basic

3-4-5 triangle. Some other students have already spent time applying the advanced Pythagorean Theorem to larger triples (e.g., 5-12-13 triples). Teaching a group of students magnifies the challenge to elicit each student's intrinsic motivation and accommodate the base of knowledge.

The issue of providing equal opportunity to all students has been extensively discussed and investigated in educational research (Elliott & Bartlett, 2016). In a “one-size-fits-all” instruction, teachers typically provide the same content of knowledge or concepts to the whole class and at the same time (Cooper, 2009). In this situation, little adjustment is made according to an individual’s learning needs. On a superficial level, this type of instruction seems to fulfill the efficiency when teaching a large group of students. Yet, the fixed instruction ignores the fact that not every student response and perceive the teaching equally well within the class. More educators pointed out this not adaptive teaching format no longer satisfies individual differences, preventing students from utilizing the same level of learning opportunity. On the opposite side of this conventional education, it is the teaching and instruction with higher flexibility, better adaptation. Therefore, many educators and researchers have continuously invested effort in dealing with individual differences in learning. In the meantime, more teaching methods and strategies have been implemented to achieve equal opportunity in a heterogeneous classroom.

To offer an equal and qualified learning opportunity for school-aged children, teaching and instruction should be sensitive to students’ heterogeneity (Lazenby, 2016; Wang & Lindvall, 1984). Hattie and Yates (2014) claimed that learner-centered teaching should accommodate individual needs. Unfortunately, the actual classroom practices have remained fixed, and the appearance of learner-centered instruction appears less frequently than expected (Snow, 1986; Warwas et al., 2011). When schools and teachers struggle with this difficulty, educational technology is now experiencing rapid development and seeing its applications in school settings. With this growth, technology is expected to deal with individual differences and to satisfy students effectively. For example, computers provide unique opportunities to an individual concerning their learning interest and motivation level. Besides, learning with hypertext was found to contribute to students’ prior knowledge (Salmerón et al., 2006). Previous research found that the use of computers and gaming tools predicted growth in individuals’ interest and engagement in STEM field learning (Subbian, 2013). The possible drive behind computer-based learning is using technology to facilitate learners’ curiosity and willingness to raise questions. By improving learning experiences (e.g., learning from playing), educational technology has unique potentials on facilitating interest and enthusiasm about learning (McLaren et al., 2017).

2.6.2 *Supporting Adaptive Teaching through Technology Integration*

The importance of providing adaptive teaching is widely recognized, and the superiority of being adaptive is widely reported in previous research (Park & Lee, 2004). Nevertheless, how to respond to students with diverse learning characteristics is still a challenge for educators. As mentioned earlier in this chapter, there are barriers to implementing adaptive teaching in classroom practices. In secondary education, the average class size was about twenty-four students per class (OECD, 2015a). Considering a seventh-grade mathematics teacher responsible for a class of students at the same time, he or she needs to deliver the instruction, organize the materials, and assess within limited class time. At this moment, if teachers are required to provide personalized teaching to each student, does it sound like a huge burden for them?

Accomplishing these challenges requires a new method to provide optimal supports to both teachers and students. To maximize the probability that individual students' characteristics and needs are well recognized and fulfilled, educators and researchers have tried a wide variety of teaching strategies and available approaches. Among these various resources, technologies provide a variety of alternatives to make instruction more adaptive. To better scaffolding individual students' learning, educational researchers attempt to explore the potentials of different tools for educational purposes (Zydney, 2010). From early to recent studies have discovered that ICT-based instruction results in greater flexibility in matching students' diverse learning needs and characteristics (Anand & Ross, 1987; Federico, 1999; Park & Lee, 2004). When teachers attempt to adjust their teaching and instruction to accommodate students' learning needs, integrating technology as a tool provides an innovative method for assisting adaptive teaching on the class level (Pilgrim et al., 2012). In this sense, the integration of technology affects the interaction between the supply and the use of these opportunities formerly unimaginable in conventional settings (Scheiter, 2017).

The advances in technology and digital tools greatly increase the alternatives to deliver information that can be used to enhance student learning. In pursuit of adaptive teaching, technology has numerous distinctive potentials. Recent studies have increasingly explored the potential of different digital tools (e.g., computers, multimedia, intelligent tutoring system, and interactive whiteboards) for developing alternative learning environments and ways to use these tools to stimulate students' cognitive development (Cheung & Slavin, 2013). *Adaptability* is one of the most crucial and noticeable potentials of technology (Merrill, 1994). Adaptability refers to the ability of ICT to adapt to different situations and expand educational opportunities through particular applications or tools (Cooley & Glaser, 1969; Paramythis & Loidl-Reisinger, 2004). Technology has the potential to individualize the teaching and learning processes in classrooms (Cooley & Glaser, 1969). Appropriate use of this potential allows students with multiple learning prerequisites to be actively involved in the learning process and take responsibility for their learning (Springer et al., 1999). Moreover, adaptability is a central ability of some intelligent technologies to capture student responses, which reflect student interest, motivation, and cognitive ability, and then use them to adapt instruction at a later point in time (Adesope et al., 2014).

The adaptive potential of technology is closely connected to adaptive teaching and positively affects student learning (Hattie, 2009). Based on a continuous reflection of student learning characteristics, technology makes micro-level adaptations and changes in instruction (Scheiter, 2017). For instance, some studies have suggested that compared with traditional instruction, technology plays an irreplaceable role in delivering a dynamic learning environment for students, which becomes the foundation for an active learning classroom. The positive consequences would encourage schools and teachers to embrace technology in teaching and learning processes gradually. Using technology to facilitate adaptive teaching could be grounded in specific classroom activities in practice (Murphy & Davidson, 1991). Recent research has also pointed out that technology has the potential to cover the presentation and processing of information and can also embrace student learning in diverse contexts (Scheiter, 2017). The advantages of technology in supporting adaptive teaching are highlighted in three aspects of adaptive teaching: teaching content, assessment, and feedback. The following paragraphs identify the integration of technology in different aspects of adaptive teaching.

Technology and Adaptive Content. In particular, technology provides teachers more chances to design instructions and learning tasks in a tailor-made condition (Clark & Luckin, 2013; Mishra et al., 2016b), to help teachers diagnose students' progress and difficulties (Durfresne et al., 2000), and to provide adaptive feedback on students' learning performance. The appropriate use of technology can activate students' cognitive processes and contribute to their deep learning (Cheung & Slavin, 2013). All these activities are not feasible in traditional classrooms.

Technology and its application are available for satisfying different teaching and learning purposes. Previous literature highlighted the availability of intelligent tutoring systems (ITS) to respond to a student's learning state and advance a teacher's instructional agenda to meet individual student needs (Greasser et al., 2012; Sleeman & Brown, 1984). Comparing the effectiveness of human tutoring, the technology was used as a supplement to classroom instruction, such as helping students' homework at home. However, rather than the computer-based system, computer technology can provide advanced functions such as offering students more control over what they learn. In this situation, a concept of learner control is acknowledged and frequently appears with adaptive content (Murphy & Davidson, 1991; Scheiter & Gerjets, 2007). Moreover, dealing with individual students with different levels of prior knowledge (e.g., advanced versus novice students), computer technology offers more possibilities for them to acquire knowledge at their pace (Federico, 1999). Other studies indicated that when students can decide what they learn from the instruction leads to better learning results (Mihalca et al., 2011). For instance, there is an application called *Knowlton,* which provides diverse course materials based on accumulated student progress information. Under the support of advanced digital technology, a wide variety of organized learning activities are available for student learning. The great strengths of new technology allow all students to make decisions regarding their learning preferences, cognitive abilities in turn contribute on their learning interest and motivation (Scheiter & Gerjets, 2007).

Technology and Adaptive Assessment. Technology has the potential to provide a diagnosis or evaluation of students' learning (e.g., prior knowledge) based on any slight changes in the previous performance (Durfresne et al., 2000). In the classroom learning context, technology is becoming more commonplace in learning activities and has been widely applied for tracking an individual's learning process (Mishra et al., 2016a). Compared to the traditional format assessment, such as mid-term tests and final examination, using technology-based assessment is unnecessary to wait for a particular time interval. Specifically speaking, the technology-based adaptive assessment has several advantages over the traditional assessment approach. First, technology provides teachers with alternatives and more flexibility in collecting student responses from multiple sources (Bennett & Davis, 2001). Second, ICT-based adaptive assessment can ideally offer an accurate and immediate evaluation of student learning outcomes (Thissen & Mislevy, 2000). This new alternative assessment enables teachers to evaluate an individual's performance throughout the learning process. For instance, technology (e.g., Clicker, or other classroom response system) allows students to answer some quick questions (Williamson Sprague & Dahl, 2010). The rapid answer timely reflects the students' current learning status or performance without disrupting the learning process (Trees & Jackson, 2007). By using technology, teachers encourage students to assess themselves at their pace. During this process, the technology-assisted format enables teachers to assess their students' performance in an informal but timely way. More importantly, based on the results from previous items, teachers can apply the follow-up assessment according to individual student's needs. Besides, the timely assessment provides teachers guidance to adapt the instruction, such as modifying the difficulty of the learning task and extending the responding time for students. In this situation, the adaptive assessment is also closely related to other components of adaptive teaching. Some other available programs and applications such as *Socrative, Kahoot, PeerGrade, and Formative* have been designed and implemented to minimize the demands on teachers' time and to provide diagnostic information about student learning. When more techniques are used as instructional tools for assessing and analyzing student learning progress, they greatly expand teachers' flexibility and ability to provide adaptive instruction.

Technology and Adaptive Feedback. Previous studies have suggested that if the feedback is timely, elaborative, and adapted to individual needs and progress, it will benefit student learning (Hattie & Timperley, 2007). However, in traditional classrooms, it is nearly impossible for teachers to provide personalized feedback to all students during the lessons. Therefore, recent research focuses on how to provide students with timely feedback that guide their subsequent learning processes (Mory, 2004). In this situation, computer-based feedback (CBF) was taken on board when advanced technology was available to offer automatic and individualized feedback on individuals' language learning (Lachner et al., 2017; Neri et al., 2008), writing (Ebyary & Windeatt, 2010), or mathematics learning (Corbalan et al., 2010). Beyond providing adaptive assessments, ICT-based instruction also has the potential to provide feedback alongside the students' problem-solving processes (Azevedo & Bernard, 1995; Ross & Morrison, 1993). For instance, computer technology can generate feedback in each step of the mathematics task until the final step (Corbalan et al., 2010). Based on the timely information, students can verify the correctness of their responses simultaneously. One possible reason that makes this timely and adaptive feedback more effective than regular feedback is that the students' attention on the problem states is consistent rather than interrupting. In other words, students can learn from an ongoing procedure that leads them with rationale examples and suggestions (Atkinson et al., 2000; Crippen & Earl, 2007). The above distinctive features of computer-based feedback significantly balance individual students' cognitive load and aid their learning (Paas et al., 2003). In addition to the above advantage in decreasing students' cognitive load while learning, Hattie (2009) claimed that the use of technology increases a teacher's flexibility in deciding when and to whom to provide feedback. As noted earlier, every student enters the classroom with individual learning prerequisites. Only with support from computer technology makes teachers possible to provide adaptive feedback in the learning environment (Bimba et al., 2017). Since feedback is optimized and used to correct students' responses rapidly, it enhances the effectiveness of using technology to support student learning in the classroom.

Bringing the unique characteristics of technology in supporting adaptive teaching, the difficulty of classroom implementation is still existing. Because effective learning cannot be achieved without students' active involvement in the learning processes, this follows the idea of how to use technology to facilitate individuals' learning interest and engagement.

2.6.3 Promoting Student Involvement in the ICT-Based Instruction

When discussing the involvement and engagement in mathematics learning, it is common to observe that many school-age children, in both genders, have experienced difficulties in actively engaged in mathematics tasks and learning activities. The teaching process supposes to provide learning opportunities to students, and its central goal is to create a classroom environment and motivate students to engage in active learning. Facing this primary objective, we may ask how we can ensure that the students are actively involved in the learning processes? The solution to this question is still unsure, and people are trying various approaches to facilitate active learning. During this process, educational technology offers some clues about the answer. Some educators suggested using technology to cognitively and motivationally engage students in learning processes (Bergdahl et al., 2020; Bond & Bedenlier, 2019). The current section takes a more in-depth look at using technology to promote student involvement in the classroom context.

Recent research found that the use of technology could foster cognitive activities by promoting students' situational interest and cognitive engagement (Mayer, 2005). Additionally, Suhr et al. (2010) suggested a positive impact of the one-to-one computer setting on a high student engagement level. In particular, technology-related instruction can be useful when teachers stimulate student cognitive engagement by integrating teaching strategies with appropriate learning content, in-class questions, and other instructional activities. More specifically, integrating technology in the classroom provides teachers the alternatives to ask questions, conduct assessments, and provide feedback. Many tablet-based applications are designed to adjust the contents and difficulties of materials suitable for students' learning prerequisites. For instance, if a student is unable to solve the problem, the difficulty of the upcoming questions will have a downward adjustment (Kingsbury & Houser, 1998). This adjustment provides the student with an opportunity to improve the interaction and think actively and continually motivated to overcome the obstacles during the learning processes (Gouli et al., 2001).

More importantly, the cause of active learning is not technology (Geer et al., 2017). It is a matter of how to use technology to engage students in the learning process (Bedenlier et al., 2020; Lindquist & Long, 2011). For instance, some researchers attempted to discover an effective way to trigger motivation via educational games (Habgood & Ainsworth, 2011). However, even though technology research is abundant, yet educators still maintain at the surface level of understanding about how technology can be used effectively during instruction (Dias, 1999). Due to the complicated interaction among technology, teaching methods, and curricular content, the effects of technology were not consistently positive (Chu, 2014; Nathan & Robinson, 2001). For instance, some studies have found inconsistent and contradict evidence regarding the magnitude of ICT-based instruction on student learning across education systems (Han & Finkelstein, 2013a; Lei, 2010; Scheiter et al., 2014; Wong & Li, 2011). The appropriate way to support teaching via technology needs further discussion. Here is a clue to situate the use of technology in the preexisting model.

As noted previously (2.2.2), when considering integrating technology in classroom activities, the SAMR model introduced by Puentedura (2003) provides useful guidance. While deciding which program should be selected and applied to facilitate higher-order learning, he suggested the technology should be used in an unreplaceable way to increase students' learning interest and engagement. When the technology is utilized so that the learning activity is easily achieved without it (i.e., substitute), the use of technology leads to a phenomenon of novelty effect (Rosenthal & Eliason, 2015). It does little to enhance the learner's progress substantially. However, when people seek to enhance students' active learning via specific technology, the SAMR model is too broad for classroom practices. Therefore, some other educators provide more vivid guidance on integrating tablet computers to promote higher-order learning. The pedagogy wheel summarizes various applications based on the SAMR model (Carrington, 2016; Zhang et al., 2018). From a different angle of technology used, Carrington's creative categorization provides teachers a concrete image of a particular mobile application's underlying educational purpose. In other words, because the categorization starts from the purpose of using the digital tool, it is helpful for teachers to consider using the same tool in different ways, which in turn can apply to actively involve their students in learning.

2.7 Overarching Research Questions and Study Focuses

According to the framework of the supply-use model, teaching and instruction are supposed to provide suitable learning opportunities to all students who vary in their learning prerequisites and individual characteristics. As outlined above (see Section 2.6), it provides insights into the use of technology to reduce individual differences. Therefore, the present dissertation proposes that ICT-based instruction has the potential to accommodate individual differences and make a positive impact on student learning processes. Moreover, when technology is integrated and utilized effectively, it is expected to contribute to students' motivational and cognitive learning processes. In this sense, I would expect that the successful use of ICT would increase the positive effect of teaching and provide sufficient support for student learning. Yet, in the empirical field, *whether* and *how* ICT-based instruction influences the student learning process has remained mostly unexplored.

From Chapter 3 to Chapter 6, the empirical parts of this dissertation explore the use of technology in real classroom settings and deepen the understanding of its influence on student learning processes. The overarching research questions targeted in the present dissertation are: (1) what is the effect of using technology on student involvement in mathematics learning? and (2) how can the integration of technology in mathematics classrooms become more effective? To improve the understanding of the interplay of the use of technology, individual learning prerequisites, and student learning processes, the present dissertation includes three empirical studies. The empirical studies in the separate chapters have various focuses on the interplay of the supply and use of learning opportunities in ICT-based instruction. Simultaneously, they build on the same framework of the Supply-Use Model and progressively explore the use of technology in the classroom environment (see Figure 2.5). To sharpen the focus on the interplay of ICT-based instruction and student learning processes, I pay attention to the supply and use levels of the model. Moreover, not all relevant variables and relationships on these two levels are considered (the variables that are not the focus of this dissertation are marked with grey frames; the relationships that are not the focus of this dissertation are marked with grey arrows).

The empirical parts of the dissertation run from Chapter 3 to Chapter 6. In general, the three empirical studies took a closer look at integrating technology in classroom environments and determined whether they led to changes in students' learning processes. Instead of only answering *whether* or *if*, the studies also provided empirical evidence on *how* educational technology has been integrated and used in German secondary schools. During this process, several constructs were selected to show their relationship with the use of technology concerning students' active learning processes.

Specifically speaking, the studies answered the overarching research questions of this dissertation in sequence. *Study 1* investigated the relationship between individual learning prerequisites and student involvement, and in which context this relationship will change. Specifically speaking, it is expected that the use of technology would moderate the relationship between learning prerequisites and student involvement in learning processes. If the changes in student learning responses were observed, *Study 2* further examined whether the positive effect of technology integration in student learning responses lasted for a prolonged period using the baseline latent change models. Additionally, it is assumed that the influence did not come from the technology per se but depends on how it was utilized. To test this expectation, Study 2 took an in-depth look at the mechanisms (how) behind integrating technology in the classroom to examine whether the quantity and quality of integration were associated with the continual changes in students' active learning.

The previous two studies found that the key to effective integration was how the technology was used for learning. The third empirical study explored the potentials of technology to support all students' learning and the circumstances under which technology compensated for differences in their learning prerequisites. *Study 3* investigated how the integration of technology would impact students' active learning by exploring its potentials on supporting adaptive teaching. The three empirical studies attempt to answer the following research questions:

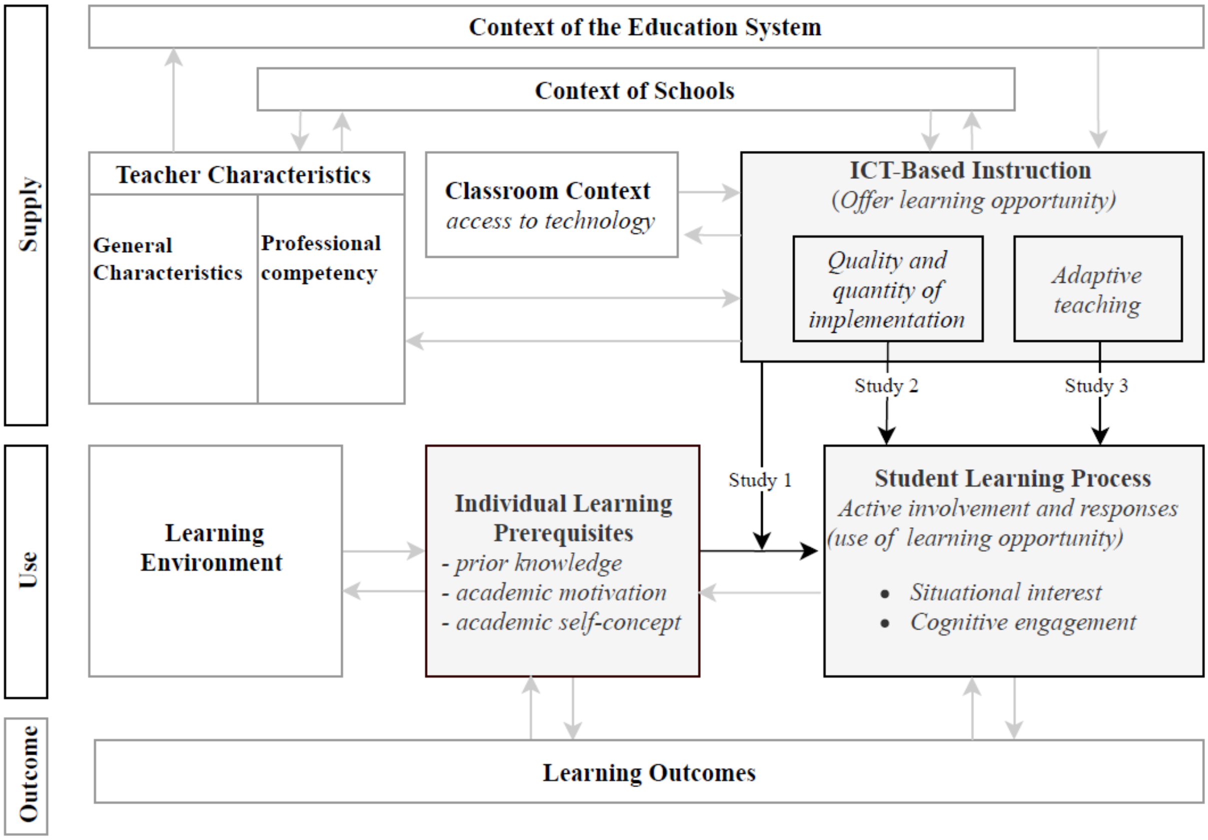
Study 1: What is the effect of individual learning prerequisites on student involvement in mathematics learning processes? Does the use of tablet computers moderate the relationship between individual learning prerequisites and student involvement in mathematics learning?

Study 2: Is the use of tablet computers in mathematic classes associated with changes in student involvement in mathematics learning over time? Are these changes associated with the quantity and quality of integration of tablet computers in mathematics classrooms?

Study 3: Do students' perceptions of adaptive teaching associated with integrating tablet computers in the mathematics classrooms? Do students' perceptions of adaptive teaching mediate the relationship between the use of tablet computers and student involvement in mathematics learning?

Figure 2.4

Theoretical Framework and Relationships Between Three Empirical Studies



Note. Adapted by permission and copyright received. From "Effects of class size and adaptive teaching competency on classroom processes and academic outcome," by Brühwiler, C., and Blatchford, P, 2011, *Learning and Instruction*, *21*, p. 95-108. The greyed blocks and italic terms are the key variables of the present dissertation.

3

Project Overview and General Method

Chapter 3 Project Overview and General Method

To investigate the effect of using technology on student learning processes in classrooms, the empirical part of the present dissertation comprises three studies. Building on the theoretical background in Chapter 2, the current chapter describes the methodological approach associated with the three empirical studies. These studies were generally embedded in a longitudinal research project called the tabletBW Meet Science project (hereafter referred to as the research project). The student data gathered from this research project were used to test the research hypotheses. The present chapter first provides an overview of the research project (see Section 3.1). Afterward, the second part of this chapter describes the general method (3.2) that is relevant to the studies and is structured as follow: study design (3.2.1), participants (3.2.2), data collection (3.2.3), and instruments (3.2.4). Building on the general method, the third part (3.3) briefly describes the relationship between the current project and three empirical studies of this dissertation, along with the corresponding measurement points and participants.

3.1 Project Overview

In 2016, the Ministry of Science, Research, and Arts (Ministerium für Wissenschaft, Forschung und Kunst, MWK) in the German federal state of Baden-Württemberg offered an educational technology grant to enhance the capacity of educational technology in upper secondary schools (Allgemeine bildenden Gymnasien). The Ministry aimed to support the use of modern technology in classroom environments by equipping local schools with up-to-date tablet computers. Subsequently, a question thereby became essential to address: When school teachers and students access to personal digital media, does it change the teaching and learning processes in practice, and how do they change? To answer this fundamental question, the Ministry initiated a school trial called *tabletBW* and invited all upper secondary schools across the state to participate in the trial. Because the school trial offered schools the chance to be equipped with one-to-one tablet computers, numerous upper secondary schools showed an interest in the school trial. A total of 56 schools applied to participate.

The school trial consisted of two parts: One was the pilot study, and the other was the main study. First of all, four upper secondary schools were randomly selected for the pilot study. These pilot schools received technology training and were then given access to the one-to-one tablet computers two months after the training. Second, when recruiting the participants for the main study, the process involved a two-stage stratified design with schools selected in the first stage and classes in the second. Twenty-eight upper secondary schools were selected for the main school trial. Later, out of these selected schools, 14 of them were randomly assigned to be the tablet schools and were equipped with one-to-one tablet computers. The other 14 schools were assigned to the non-tablet schools that did not receive any digital devices from the trial. Starting from the academic year 2017/2018, two classes of seventh graders (Cohort 1) in each school took part in the study. One year after the initial participation of Cohort 1, two more classes of seventh graders from the same school participated in the school trial as a new cohort (i.e., Cohort 2, academic year 2018/2019).

In educational research, a major factor that limits researchers' knowledge about technology-enhanced learning is the availability of technology-integrated classrooms. Before initiating this school trial, the lack of access to up-to-date devices in education practices has impeded empirical research in ICT-based contexts. That is, the current school trial not only brings top-down changes in schools' technology environment, but it also provides educational researchers with an opportunity to investigate the use of technology as a learning tool in real classroom settings. Embedded in the school trial, the Hector Research Institute of Education Science and Psychology (HIB) at the University of Tübingen and the Leibniz-Institut für Wissensmedien (IWM) launched an interdisciplinary research project called *tabletBW Meets Science* (addressed as a research project).

The research project is designed as a 5-year longitudinal study for investigating the use of one-to-one tablet computers in diverse academic subjects' classrooms (i.e., mathematics, the German language, history, biology, and English). The primary purpose of this research project is to systematically investigate conditions and possible factors for the sustainable and effective use of ICT for teaching and learning in classrooms. In this project, the research team comprises interdisciplinary researchers from educational science and psychology. We collaborate with the local upper secondary schools to unfold the black box of teaching and learning processes and to evaluate the utility of ICT in classroom practices. To provide a comprehensive understanding of ICT and its implementation, the project collects data from teachers, students, and parents. By conducting the empirical field study in real school settings, we aim to strengthen our understanding of the requirements for integrating ICT and gather more evidence to advance early learning theories.

The present dissertation focuses on the interplay of technology and students' learning processes and how technology influences learning in the school context. The empirical part of the dissertation involves three studies that targeted school students and used student data to deepen the understanding of ICT-based learning. The following sections provide a methodological foundation for the three empirical studies and address the method relevant to student participants.

3.2 General Method

3.2.1 Study Design

The research project was designed as a longitudinal study. As describes earlier in this chapter, the randomized controlled was conducted at the school level. The schools were randomly assigned to (1) non-tablet or (2) tablet conditions. In the current research project, we used repeated observations and measures to follow individual students' changes in both conditions. The participants from the same types of conditions received similar manipulations with identical administrative processes and natural observation. To reduce the potential for biases that often appear in observational studies, we carefully controlled for possible differences between the non-tablet and tablet class settings.

Specifically speaking, the existing project used several approaches to avoid significant differences in covariates between the groups. First, to ensure that students' situations and prior learning experiences were identical initially, the tablet and non-tablet classes had not previously integrated the one-to-one tablet computers in daily schooling. Second, in the same classroom setting, we administered a pretest to measure all participants' baseline performances, individual characteristics, and perceptions of instruction and learning. The only difference between the two conditions was that the teachers and students from the tablet classes could access personal tablet computers during their school routines.

After the initial assessment, the tablet classes were equipped with tablet computers. During the study, teachers and students at the tablet schools had the authority to use the tablet computers as learning tools to present academic materials, create an interactive learning experience, or plan any learning activities inside the classrooms. Because the current project was designed to be an observational study, we did not manipulate the selection or use of tablet computers. Teachers in the tablet classes had the authority to decide how frequently their students should work on the tablets and which kinds of software to use in their teaching.

Additionally, the current research project gathered quantitative student data with a variety of instruments with different formats. We conducted a prospective research design and planned six waves of measurement to track the same groups of students across time. One central purpose of the continuous measures was to examine the relationship between the use of tablet computers and students' development and particularly the effect of tablet integration across different lengths of time. During this process, students' perceptions, abilities, and experiences of using technology were assessed in two parts: a) cognitive test and b) student questionnaire. Table 3.1 summarizes the instruments for each measurement point and the administration processes.

Table 3.1

Overview of the Measurement Implementation Process

Measurement point	Instruments	Mode of delivery	Duration
First	Cognitive tests	Paper-based	70 min
	Student questionnaire	Computer or paper-based	110 min
Second	Student questionnaire	Computer or paper-based	90 min
Third	Student questionnaire	Computer or paper-based	90 min
	ICT literacy test	Paper-based	15 min

Note. The above administration processes were consistent between Cohort 1 and Cohort 2. At the first measurement point, the cognitive tests include mathematical test, German language test, ICT literacy test, and reasoning test. During the assessment, due to some technical difficulties (e.g., Internet connections, the supply of digital devices), the student questionnaires were delivered in a paper-and-pencil-based format for some schools.

The first part covered a range of cognitive tests. In this phase, we examined each student's general cognitive abilities and subject-specific knowledge as well. Since the measured variables of the cognitive tests were assumed to be relatively stable across the measurement points, they were assessed only at the baseline measurement wave. The second part involved a student questionnaire, which was conducted at each measurement point. The student questionnaire assessed students' attitudes toward and their opinions and perceptions of teachers, instruction, and experiences in the subject-specific classrooms. Depending on the technological conditions in the individual schools, we delivered the student questionnaires in either a paper format or a computer format. Additionally, four paper-and-pencil based standardized cognitive tests were administered to measure students' cognitive competence, including domain-specific prior knowledge, general cognitive abilities, and ICT literacy skills. More supporting information about the content of the cognitive tests and questionnaire items would be described later (3.2.4).

For each measurement point, the trained research assistants delivered the instruments and materials to the schools. The assessment took place in a quiet classroom under the supervision of a teacher and two research assistants. Besides, the full assessment was administered during the regular school day. At the beginning of the measurement, the research assistants provided a brief introduction about the project, including the research purpose. Only students who submitted the consent forms were allowed to participate. During the introduction, all the participants were informed that participation was voluntary, and they were encouraged to seek further clarification if needed. They were told that their responses would be anonymous and would be kept confidential. Depending on the specific measurement point, students either worked on the questionnaires together with cognitive tests or the questionnaire only. Consequently, we could make a longitudinal comparison of students' characteristics and learning experiences. More supporting information on the data collection processes would be described later (3.2.3).

3.2.2 Participants

A total of 2,610 students voluntarily participated in the current longitudinal research project. Between the first and second measurement points, the participants were from the two cohorts, which initially joined the research in Grade 7. At the baseline measurement point, the students' average age in Cohort 1 was 13.35 years (*SD* = 0.56), ranging from 12-18 years old. Additionally, as illustrates in Tablet 3.2, the average age in Cohort 2 at the baseline measurement point was 13.37 years (*SD* = 0.55), ranging from 12 to 15 years old.

Based on the study design, roughly half of the participants were studying in the non-tablet class condition, and the second half of them were in the tablet class condition. Table 3.3 presents the sample size at each measurement point and displays the numbers of participants in the corresponding cohort and condition.

Table 3.2

Descriptive Statistics of Two Cohorts of Students across Three Measurement Points

Cohort	*n*	Gender		Age			
		Male (%)	Female (%)	*M*	*SD*	*Min*	*Max*
First measurement point							
1	1,278	589 (50.4%)	579 (49.6%)	13.35	0.56	12	18
2	1,127	515 (49.6%)	523 (50.4%)	13.37	0.55	12	15
Total	2,405	1104	1102				
Second measurement point							
1	1,173	587 (49.1%)	608 (50.9%)	13.39	0.68	12	18
2	1,083	527 (48.8%)	552 (51.2%)	13.41	0.68	12	19
Total	2,256	1114	1160				
Third measurement point							
1	719	329 (46.1%)	385 (53.9%)	14.31	0.55	13	19

Note. This table demonstrates the number of participants of each cohort, alongside with the demographic information. The total sample size of Cohort 1 and Cohort 2 students, $N = 2610$.

Table 3.3

Overview of Samples by Measurement Points, Cohorts, and Conditions

Measurement point	*N*	Condition	Cohort		*n*
			1	2	
First	2,251	Non-tablet class	613	429	1,042
		Tablet class	541	668	1,209
Second	2,236	Non-tablet class	575	441	1,016
		Tablet class	594	626	1,220
Third	706	Non-tablet class	173	—	173
		Tablet class	533	—	533

Note. $N = 2{,}610$. The students in Cohorts 1 and 2 both attended the first and second measurement points. Since the academic year 2017/2018, Cohort 1 has joined the research project, whereas the initial participation of Cohort 2 was in the academic year 2018/2019. Hence, until the last data collection, Cohort 1 has participated three times.

3.2.3 Data Collection

The student questionnaires and cognitive tests were making up the current quantitative research. During this process, student data were collected from the participants in both the tablet and non-tablet classes. We planned to conduct six repeated measures to collect the student data and make a comparison within and between participants at the individual level, as well as to compare the tablet and non-tablet conditions at the class level. In the present project, the primary purposes of collecting student data were to assess student variables at a single measurement point and follow particular students' learning over a more extended period. In general, the data were collected from two cohort panels wherein the same design was used for the participants in a defined condition (either tablet or non-tablet classes). As shown in Table 3.4, we conducted the data collection (t_{ij}) during the academic semesters in schools, where Cohort 1 (i = 1) and Cohort 2 (i = 2) participated j measurements with different initial periods (t_{i0}). Up until July 2019, three measurement points were completed for Cohort 1 and two measurement points for Cohort 2.

Table 3.4

Overview of Periods, Grade Levels, and Cohorts at Each Measurement Point

Grade 9					Cohort 2 (t_{22})
Grade 8				Cohort 1 (t_{12})	Cohort 1 (t_{13})
Grade 7	Cohort 1 (t_{10})	Cohort 1 (t_{11})	Cohort 2 (t_{20})	Cohort 2 (t_{21})	
Time period	Spring 2018	Summer 2018	Spring 2019	Summer 2019	To be announced

Note. This chart demonstrates the data collection (t_{ij}) for the cohorts (i) and the measurement points (j) that participated. Each cohort of participants was assigned to either a tablet class or a non-tablet class. Those values within the parentheses, t_{10} = Cohort 1's first measurement point, and t_{20} = Cohort 2's first measurement point. For practical reasons, the actual launch time for the fourth wave of measurement for Cohort 1 (t_{13}) and the third wave for Cohort 2 (t_{22}) has not yet been confirmed.

Specifically, data collection began in February 2018 when the students in Cohort 1 participated in their first round of data collection (t_{10}; baseline measure). This baseline measurement included the pretest from the student questionnaire and four other cognitive tests. None of the schools in the tablet class condition had integrated tablet computers into their classrooms. After 4 months, the second measurement point (t_{11}) took place in June 2018. We repeatedly collected the student data from the same cohort (Cohort 1). At this second measurement point, the students in the tablet classes had used their tablet computers for the whole semester. Hence, we inserted additional tablet-relevant items into the tablet classes' questionnaires to gather information about integrating technology and the relevant learning experiences. The third measurement point (t_{12}) took place 12 months after the previous one, and we collected the data from the same cohort of students. These participants repeatedly responded to the student questionnaires and took the ICT literacy test.

Data collection for students in Cohort 2 began in February 2019 (t_{20}, baseline measure). At this initial time point, we employed the same study design and organization process as in Cohort 1. All participants in the tablet condition also had not yet accessed any one-to-one tablet computers in the classroom environment. At this baseline measurement point, we used the same student questionnaires as in Cohort 1 and administered four cognitive tests to assess the students' cognitive performance. Four months after the first measurement, the next measurement wave (t_{21}) took place in June 2019. Here, the same students in Cohort 2 participated in their second round of data collection. Because the students in the tablet condition had accessed and used tablet computers for the whole semester, they were asked the additional tablet-relevant questions regarding their utilization of tablets on particular occasions.

In sum, from February 2018 until July 2019, we continually collected student data from Cohort 1 for 16 months. We followed the students from Cohort 2 for 12 months and conducted two data collection points with them. As the research project keeps going, data collection will continue. However, for practical reasons, the next round of data collection has yet to be determined (i.e., the fourth measurement point [t_{13}] for Cohort 1 and the third measurement point [t_{22}] for Cohort 2).

As a longitudinal research project, the data collection highly relied on respondents' continued participation. During this process, however, we were facing the issues of missing data at each measurement wave. There were various mechanisms behind missing or incomplete data due to systematic or unsystematic reasons (Allison, 2001; Hofer & Hoffman, 2007; Scheffer, 2002). In the present research, the first reason was the dropout of the participants at the school level. For instance, at the third measurement wave for Cohort 1 (t_{12}), eight out of 14 non-tablet schools decided not to participate in the study again. This dropout was due to the internal school decisions that were unpredictable. The second cause of missingness was the item nonresponse that occurred on some participants. For instance, while answering the questionnaires, some students skipped certain individual items because they did not know how to answer or refuse to answer, or accidentally missed the questions. According to Schafer and

Graham (2002), the mechanism of missing values in the current research was assumed to be missing at random (MAR).

3.2.4 Instruments

In the research project, we administered a selection of instruments to collect the perceptions of teachers, students, and parents regarding their perceptions, abilities, the use of technology, and other characteristics on different occasions. As noted previously, since the present dissertation focuses on the interplay of technology-based instruction and student learning processes, the empirical part only used the student data for the analyses. Thus, the following paragraphs focus on the instruments designed to gather students' perceptions, performance, and responses regarding their learning experiences. The survey instrument comprises two parts: (a) student questionnaire and (b) cognitive tests.

Student Questionnaire. Student questionnaires have been the essential components of the current research project from its beginning (i.e., the retrospective measures based on the student self-report inventory for assessing individual differences in learning processes). Additionally, student self-reports provide significant advantages for collecting a large amount of quantitative data in a standardized way (Schmeck et al., 1977). In the present research project, the student questionnaires were designed to collect student responses in their subjective experiences in school. In particular, the questionnaires assessed students' perceptions of their teachers, instruction, computer-based delivery, and personal characteristics in learning. The student questionnaire included Likert-type responses to items and a small number of open-ended questions.

In general, the questionnaire was divided into two subsections. The first subsection assessed students' demographic information, including age, gender, migration background, and family information, adapted from the items from PISA 2015 (Mang et al., 2019). The second subsection consisted of three main components: (a) tablet-related variables that were associated with the tablet class condition (i.e., students who used tablet computers in school); (b) student variables that covered the individuals' affective, emotional, motivational, and behavioral characteristics in learning; (c) instruction and teaching variables that indicated teaching practices and the quality of instruction. The selected scales were adapted from the published questionnaires.

When measuring the student and instruction variables, the scales and items were designed to target respondents' subject-specific experiences corresponding to school subjects.

The five core subjects for seventh graders were: mathematics, the German language, history, biology, and English. For all of the items, the wording was strictly parallel except for the name of the specific academic subject (e.g., "In [a particular subject class], it was important for me to understand things very well."). For example, the situational interest (SI) subscale contained five items for assessing individual students' joyfulness regarding a particular school subject. When answering the SI scale that targeted the experiences in mathematics class (SIM), the respondents rated the degree to which they were interested in mathematics (e.g., "In the mathematics classes, the teaching captured my attention"; Knogler et al., 2005).

For each subject-specific item, the respondents provided retrospective answers about whether they had used tablet computers or not. For instance, at the baseline measurement point (t_{10} and t_{20}), the questionnaires were consistent between the tablet and non-tablet groups. However, starting from the second measurement point (t_{11} and t_{21}) and the subsequent waves, the questionnaires administered to the tablet-group students were different from the questionnaires administered to the non-tablet group. The tablet-group questionnaire consisted of two parts: (a) tablet-relevant items and (b) non-tablet-related items. In responding to the different patterns of items, the participants needed to recall the corresponding subject-specific learning experiences of (not) working with tablet computers. Responding to the items, the students gave answers on a Likert-type rating scale that closely represented their viewpoints (e.g., 1 = *not apply at all*; 4 = *totally apply*). Since the students were asked to directly recall personal past learning experiences, their retrospective responses should accurately capture their actual state of mind during instruction and reflect their evaluation.

Moving from the research project to the current dissertation, the empirical studies of this dissertation concerned the student learning and the use of tablet computers in mathematics classes. This dissertation implemented different assessments to answer the hypothesized research questions in each study. *Study 1* used two scales to assess the students' individual learning prerequisites, including motivation and academic self-concept in mathematics (see Appendix A1). Besides, as another crucial concept of this study, student involvement in mathematics learning was measured by two scales: situational interest scale and cognitive engagement scale (see Appendix A3). In *Study 2*, in order to take an in-depth look at the mechanism of tablets use, the measures involved students' perceptions of learning activities in mathematics classes (e.g., to do simulation, to do calculation; see Appendix A4). Additionally, *Study 3* covered three student-perceived adaptive teaching scales designed to measure the students' perception in terms of adaptive content, adaptive assessment, and adaptive feedback (see Appendix A3). In the above measurement scales, the participants in the tablet and non-tablet class conditions rated their agreement with the given statement on a Likert-type scale.

Cognitive Tests. In addition to the student questionnaires, the current research project also administered four paper-and-pencil tests at the baseline measurement point. We used the student data to evaluate the participants' cognitive abilities in different domains (e.g., mathematics, language, ICT literacy, and reasoning).

As the focus on students' prior knowledge in mathematics, the empirical study of this dissertation used the scores obtained from the mathematical test. Due to the limited measurement time, we administered a subset of the German Mathematics Test for Grade 9 (Deutscher Mathematiktest für neunte Klassen, DEMAT 9), named the Supplementary Tests of Convention and Rule Knowledge (Ergänzungstests Konventions- und Regelwissen, KRW). The KRW test comprised a total of 57 calculation items in a short-answer format. The items in KRW primarily aims to provide a quick assessment of students' mathematics performance in algebra (Schmidt et al., 2013). The items covered different topics of the math curriculum, such as division, ratios, and fractions (e.g., $\frac{2}{3} + \frac{1}{3} = \_\_$). To do so, the participants were asked to give answers to the items without using a calculator. The KRW test scores were used as an indicator of students' mathematical prior knowledge in the empirical part of the dissertation.

The other three cognitive tests were not directly relevant to the focus of this dissertation. The tests that were not mentioned in detail were all well-administered to measure the students' cognitive competence in other domains. For instance, we selected the Reading Speed and Comprehension Test (Lesegeschwindigkeits- und Verständnistest für 5 bis 12 Klassen, LGVT 5-12+) to measure seventh-graders' German language ability (Schneider et al., 2017). Additionally, to examine students' reasoning ability, we included the Cognitive Ability Test for Grade 4 to Grade 12 (Kognitiver Fähigkeitstest für 4. bis 12. Klassen, KFT 4-12), which was initially designed to identify gifted students (Heller & Perlech, 2000). Moreover, we used the Technological and Information Literacy Test (TILT) to assess students' declarative knowledge and procedural knowledge needed for their routine tasks (Senkbeil et al., 2013).

3.3 Present Empirical Studies

The previous sections provided a first glimpse of the school-based trial and the research project. Additionally, this chapter introduced the study design, participants, and instruments that served as the methodological foundation for the empirical studies in the present dissertation. Building on the general methodology, across from Chapters 4 to 6, the student data obtained from the current research project were used to answer the hypothesized research questions in three empirical studies.

Depending on the research focus and hypothesized research questions, the empirical studies of this dissertation included different parts of the student data from the current research project. As an illustration, Table 3.5 presents an overview of three empirical studies with the corresponding measurement points and student sample. Explicitly speaking, to investigate the effect of using tablet computers on students' active learning in mathematics classes, *Study 1* included two cohorts of participants in the sample and used data from the second measurement point (t_{11}, t_{21}). Based on the findings in the former study, *Study 2* expanded the focus to the short-term and long-term effects of tablet-integration by analyzing the sample from Cohort 1 across their first (t_{10}) to third (t_{12}) measurement points. Identical with Study 1, *Study 3* involved both cohorts and analyzed the data at the second measurement point (t_{11}, t_{21}) to explore how technology-integration would influence the student learning process.

Table 3.5

Overview of the Relevant Measurement Points and Participants in the Three Empirical Studies

<table>
<tr><th>Period</th><th>2018 Feb</th><th>2018 Jun</th><th>2019 Feb</th><th>2019 Jun</th><th>2020 Jun</th></tr>
<tr><td>Measurement point</td><td>t_{10}</td><td>t_{11}</td><td>—</td><td>t_{12}</td><td>t_{13}</td></tr>
<tr><td rowspan="3">Cohort 1</td><td></td><td>Study 1</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Study 2</td><td></td></tr>
<tr><td></td><td>Study 3</td><td></td><td></td><td></td></tr>
<tr><td>Measurement point</td><td>—</td><td>—</td><td>t_{20}</td><td>t_{21}</td><td>t_{22}</td></tr>
<tr><td rowspan="2">Cohort 2</td><td></td><td></td><td></td><td>Study 1</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Study 3</td><td></td></tr>
</table>

Note. This chart provides an overview of the corresponding measurement point and sample for each empirical study. t_{11} = Cohort 1's first measurement point. t_{21} = Cohort 2's first measurement point.

Continuing on the research focus, it is necessary to emphasize that all three empirical studies focus on the use of tablet computers and how it impacts students' learning processes in mathematics classrooms. Explicitly speaking, three criteria guided the selection of mathematics instruction as the context of this topic: (a) Mathematics, as a core subject in the school curriculum, is compulsory for all seventh graders in the upper secondary schools. (b) More importantly, the mathematics skill is essential for solving real-world problems and need for a higher order of individual thinking (Brown et al., 2011). As a crucial competence that acquires through schooling, students' motivational and cognitive characteristics related to math have been gaining attention for a long time (Wang & Goldschmidt, 2003). (c) For practical reasons, more tablet-related applications and software are available for mathematics education. The market provides more alternatives for math teachers to integrate the applications into their classes. The statistics of the current project showed that compared to other school subjects, on the one hand, the math teachers from the tablet classes reported more applications that were used for teaching and instruction, such as GeoGebra, kstools, Mathebattle, and MathGraph. On the other hand, among the five school subjects (i.e., Mathematics, German, History, Biology, and English) assessed in the research project, the tablet computers were used the most frequently in the mathematics classes at the second measurement point. Only when the tablet computers were implemented in the classrooms could we take it as a starting point to investigate how the tablets were used for learning.

Mathematics education and ICT-based instruction are two crucial topics for educational research. However, integrating technology in the mathematics classroom is a complicated process, and we have limited knowledge of it. Therefore, situated in the research project, the current dissertation explores how tablet computers are being used in this subject-specific learning context. It might open the window on the effect of technology on students' learning processes.

3.4 Acknowledgments

The one-to-one tablet computers used in the tablet classes were funded by the Minister of Education in the German federal state of Baden-Württemberg, who initiated the tabletBW school trial. As a collaborative project, at each measurement point, data collection was supported by the project coordinators and the trained research assistants from the Hector Research Institute (HIB) at the University of Tübingen and the Leibniz-Institut für Wissensmedien (IWM).

4

Student Involvement: The Effect of Individual Learning Prerequisites in the ICT-Based Instruction

Chapter 4 described *Study 1* and reported the method and results in details. The development of research questions and preparing the analytic approach were supported by my supervisors. I am grateful for the comments given by the dissertation committee. Therefore, in the 4.2 Research Question and 4.3 Method, the plural form of the first person “we” was used to address team effort. But the body of the present chapter was written by the sole author.

Chapter 4 Student Involvement: The Effect of Individual Learning Prerequisites in the ICT-Based Instruction

This chapter focuses on the equality of learning opportunities for all students with different learning prerequisites. When tablet computers are integrated into the classroom, they may change the instructional environment and learning nature. The conventional assumptions about teaching and learning are not sufficient to understand student learning processes in modern education. With awareness of these issues, the present chapter explores whether using tablet computers changes student involvement in learning processes. Building on the general methodological approach in the previous chapter, the current empirical study (*Study 1*) first explored the relationships between individual learning prerequisites and student involvement in mathematics classrooms. Building on the findings, the study considered the learning conditions of tablet and non-tablet classes. It investigated whether the relationship between learning prerequisites and student involvement was different between the two conditions. This chapter outlines the empirical findings of the analyses by using the student data of the tabletBW research project.

4.1 The Present Study

Educational researchers pointed out the importance of student characteristics to effective learning and academic performance (Fleming & Malone, 1983; Seidel, 2006). Based on the focus on student factors, the supply-use model also highlighted that some student characteristics play a crucial role during learning processes are treated as prerequisites or preconditions for deliberate learning behaviors (Bransford et al., 2000; Helmke & Schrader, 2013).

For decades, teaching practices have faced challenges in dealing with individual students' diverse needs and learning characteristics. Some individual student characteristics are prerequisites for students to effectively use the learning opportunities provided in classroom processes (Helmke, 2007; Seidel, 2014a). Specifically, this theoretical framework revealed that students have a wide variety of motivational and cognitive learning prerequisites reflected in their learning processes and activities (Helmke & Schrader, 2013; Snow, 1986). Therefore, individual differences in learning prerequisites lead to various uses of given opportunities. When studying in the same classroom, individual students vary in their learning prerequisites, such as prior knowledge and academic self-concept. These differences account for the effectiveness of student learning. Inequality occurs when some students use opportunities to learn less effectively than other classmates. Support for the student learning prerequisites is critical for all students to experience fairness in learning and in turn enhance their learning effectiveness. The present study investigated the domain specificity among the individual learning prerequisites by exploring their relationships with student involvement in mathematics learning in schools.

Specifically, recent learning theories highlight the vital role of student characteristics in teaching and instruction. For instance, some researchers pointed out the importance of eliciting active and meaningful learning processes for all students, such as enhancing their situational interest (Renninger & Su, 2012) and cognitive engagement (Fredericks, 2004). As discussed previously in Chapter 2, situational interest and cognitive engagement are two critical components of student involvement in learning processes. Specifically, as a subject-specific temporary state of interest in a particular learning task or activity (Hidi et al., 1992), situational interest can positively predict a student's knowledge-seeking behavior (Rotgans & Schmidt, 2011). Moreover, previous literature found that a student's cognitive engagement, indicating his or her degree of mental effort and allocation of attention to solving challenging tasks, significantly influences that student's learning (Fredericks & McColskey, 2012). Both constructs are highlighted as essential factors to actively engage individual students in their learning tasks and activities. The attention to student involvement raises a critical issue in educational research: How can teaching and instruction ensure that all students have an equal opportunity to learn and be actively involved in learning processes (Mcllrath & Huitt, 1995)?

In addressing this question, the advance in educational technology brings an alternative solution to the individual differences in learning prerequisites (Scheiter & Gerjets, 2007). Early research had some positive conjectures regarding the integration of technology. To understand what effects the integration of technology might have on students' learning processes in instruction, we based our work on current teaching and learning models to understand the complex interaction processes in classrooms. Regarding the potential effect of using technology, an underlying assumption of ICT-based instruction is that it significantly facilitates student learning. However, ICT-based instruction does not automatically lead to positive effects on student learning processes (Selwyn, 2010).

From a theoretical perspective, existing learning theories, such as the supply-use framework, do not formally explain the relationship between learning prerequisites and student learning processes in twenty-first-century classrooms that integrate modern technologies.

Recent research has often focused on learning outcomes and emphasized their profound influence on academic performance. For instance, researchers have investigated how teaching processes could generate satisfying learning products (Bloom, 1976; Dunkin & Biddle, 1974). On the students' level, prior studies suggested that students' academic self-concept (Marsh, 1993; Skaalvik & Hagtvet, 1990), prior knowledge (Dochy, 1994), and interest (Rotgans & Schmidt, 2011) were the significant predictors of learning performance. Compared with the many output-oriented studies, the effect of teaching and instruction on the student learning process is a relatively neglected topic.

Previous studies did not find consistent positive evidence of the effect of technology on student learning from a research perspective. Additionally, insufficient research has been conducted to uncover the effect of technology on learning processes. Few studies have compared ICT-integrated classrooms with traditional ones in real school settings (Cheung & Slavin, 2013; Dumont & Istance, 2010; Prinsen et al., 2007). Therefore, from theoretical and practical perspectives, there is a limited understanding of the relationship between students' learning prerequisites and their learning responses in ICT-based contexts. Educational researchers do not fully understand the variables and relationships in ICT-based instruction. Therefore, the primary objective of this study was to provide empirical evidence of whether students with diverse learning prerequisites could benefit from the use of technology in the classroom. Specifically, the present study was conducted to investigate the effect of individual learning prerequisites on student learning responses, and in which conditions this influence changes. To achieve this goal, we disentangled two specific research questions and associated hypotheses.

4.2 Research Questions

Following the theoretical background, the individual learning prerequisites for mathematics learning contain three main constructs: prior knowledge in math, intrinsic motivation in math, and math self-concept. The first research question aimed to identify the impact of three learning prerequisites on student involvement in mathematics classrooms. Regarding student involvement in mathematics learning, the current study focused on whether students motivationally (i.e., situational interest) and cognitively engaged (e.g., cognitive engagement) in learning processes. Moreover, to test the effect of learning prerequisites on student involvement, we also explored in which condition (non-tablet class vs. tablet class) these learning prerequisites had a different impact (weaker) on student involvement. Therefore, the following research questions were addressed:

In previous literature, many educational researchers have long acknowledged the importance of student characteristics such as motivation, self-concept (Denissen et al., 2007; Marsh et al., 2006), and prior knowledge (Tobias, 1994) in student learning. Recent learning theories and models also emphasized that some of the student characteristics were the critical prerequisites or precondition for an individual to perceive and use the learning opportunities (Helmke & Schrader, 2013; Seidel & Shavelson, 2007). Based on the early research, the current study takes an in-depth look at particular individual learning prerequisites and explores their influence on student learning processes in mathematics classes.

RQ1: Do individual learning prerequisites affect student involvement in mathematics classes?

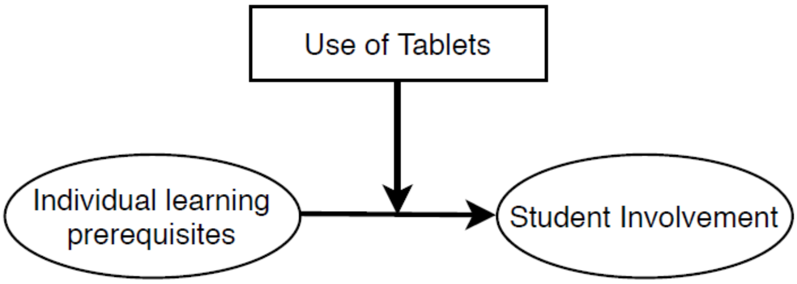
Regarding the relationship between individual learning prerequisites and student involvement in mathematics learning, we expected that better prior mathematics knowledge significantly predicts higher levels of student situational interest and cognitive engagement in mathematics classes. In addition, we hypothesize that higher intrinsic motivation predicts higher levels of situational interest and cognitive engagement. Furthermore, we expect higher reported academic self-concept in math to predict the higher situational interest and cognitive engagement in mathematics.

RQ2: Does the use of tablet computers moderate the relationship between individual learning prerequisites and student involvement in mathematics classes?

Some researchers pointed out a decline occurs in students' mathematics interest during adolescence (Frenzel et al., 2010; Frenzel et al., 2012). Different from the findings in the regular classroom settings, other researchers identified the positive impact of technology use on students' mathematics learning attitudes (Nguyen et al., 2006) and self-concept (Sivin et al., 2000). Moreover, some positive influences of using technology were found in student motivation (Matthew, 1997). Based on this previous literature, the use of technology is assumed to have the potential to compensate for individual learning prerequisites. In other words, it is reasonable to expect a change (e.g., weaker connection) between the individual learning prerequisites and the student learning process. Based on this assumption, we expected the use of tablet computers to interact with individual learning prerequisites in predicting student learning responses (see Figure 4.1). In particular, we hypothesize that under the condition of using tablet computers, students' prior mathematics knowledge, intrinsic motivation, and academic self-concept have a smaller influence on their situational interest and cognitive engagement.

Figure 4.1

Conceptual Diagram of the Moderation Analysis



Note. This figure is the simplified conceptual diagram. In the moderation model, the construct of individual learning prerequisites included prior mathematical knowledge, intrinsic motivation, and academic self-concept in math. Regarding the construct of student learning responses, it contains situational interest and cognitive engagement in mathematics.

4.3 Method

4.2.1 Sample

The current study used student data from the second measurement point of the tabletBW research project. For the purpose of this study, the analyses draw on a total of 2,286 seventh graders from twenty-eight upper secondary schools in southern Germany. All participants were from the same grade but represented two cohorts: 1,203 students (49.1% male) came from Cohort 1. The average age of the participants from Cohort 1 was 13.39 years old (*SD* = 0.68), ranging from 12 to 18 years. 1,083 of the students were from Cohort 2 (48.8% male), ranging in age from 12 to 19 years old (*M* = 13.41, *SD* = 0.68). For the whole sample, 1,048 students were assigned to the non-tablet class condition, and 1,238 students were assigned to the tablet class condition. The participants in the latter condition had worked with personal tablet computers for four months in their mathematics classes.

4.2.2 Measures

Student Learning Prerequisites. In the current study, participants' learning prerequisites were the predictor variables. To identify different student prerequisites, we assessed three aspects of student characteristics using a cognitive test and student questionnaire. The selected scales were adapted from the standardized test and published questionnaires. Across the measures, Cronbach's alpha (α) was chosen to assess the internal consistency of the items in the selected instruments.

Prior mathematics knowledge, as a cognitive dimension of individual learning prerequisites, refers to a learner's subject-specific knowledge that existed before learning. We administered a standardized paper-and-pencil-based test, named the Supplementary Tests of Convention and Rule Knowledge (Ergänzungstests Konventions- und Regelwissen, KRW) to assess the participants' prior mathematics knowledge (Schmidt et al., 2013). The KRW is a sub-test of the German Mathematical Test for Grade 9 (Deutscher Mathematiktest für neunte Klassen, DEMAT-9). Specifically, the KRW test contained fifty calculation questions in short-answer format (e.g., 5 – (3 – 2) = ___), which provided a quick evaluation of students' mathematic competence in algebra. The participants had three and a half minutes to complete the KRW test without using a calculator. For more information on the sample items in KRW, please refer to the original test.

Intrinsic motivation in mathematics, as an affective-motivational learning prerequisite, describes a student's enjoyment that motivates their learning behaviors. In the present study, we measured this subject-specific interest and inherent pleasure using three items based on the Interest/Enjoyment subscale of the Intrinsic Motivation Inventory. The students were provided with statements (e.g., "I enjoy working on the topics in mathematics") and were required to indicate their perception on a 4-point Likert-type scale from 1 (*does not apply at all*) to 4 (*totally applies*). The selected items had a high internal consistency (α = .93). More examples of questionnaire items are presented in Appendix A1.

Math self-concept, as another non-cognitive learning prerequisite, is defined as a person's self-perceived competence related to past experiences. We used four items (including two reverse worded items) to assess students' beliefs about their mathematics abilities and performance. The items were rated on a 4-point Likert scale from 1 (*does not apply at all*) to 4 (*totally applies*). The selected scale was adapted from the DISK-Gitter used in various national studies (Rost et al., 2007). The students indicated their agreement with statements such as "Mathematics is easy for me." A sample item with reversed wording was, "I always have a problem in learning mathematics." The reliability of the math self-concept scale was fairly high (α = .73). More information about the questionnaire items is presented in Appendix A1.

Student Involvement in Mathematics Learning. The present study examined two constructs of student involvement in mathematics learning processes as the outcome variables: (1) situational interest and (2) cognitive engagement. Since both constructs were difficult to observe directly during classroom processes, we used the student self-report questionnaire items to assess the extent of students' involvement and engagement in mathematics classes. The scales were generated to reflect student involvement along a continuum. Students were asked to respond to the statements in the questionnaire based on their experiences in the past four months in mathematics classes. The wording of the scale items was strictly parallel, except for the distinction between the tablet and non-tablet class conditions. The students from both conditions rated their perception on a 4-point Likert scale, ranging from 1 (*does not apply at all*) to 4 (*totally applies*).

Situational interest in mathematics, as a subdimension of the construct of interest, refers to a learner's temporary engagement that is stimulated in the learning environment. We selected five items to measure students' short-term affective learning responses (e.g., "When I worked with/did not work with the tablet computer, the mathematics instruction captured my attention,"; adapted from Rimm-Kaufman et al., 2015). The students were asked to rate their agreement with the given statement based on their past learning experiences in mathematics instruction. This published scale has previously been used to assess the extent to which a situation attracts a student's interest. The selected items were successfully applied in past studies to evaluate students' motivational engagement in learning tasks. The internal consistency was high for this scale (α = .97). More supplementary questionnaire items are presented in Appendix A3.

Cognitive engagement in mathematics, as the second construct of student involvement in the learning process, describes an individual's mental effort invested in mastering learning tasks or skills (McKolskey, 2012). We used a 3-item self-rating scale to assess student cognitive engagement (Rimm-Kaufman et al., 2015). Depending on the condition of the students, a sample item was "When I worked with/did not work with the tablet computer in this mathematics class, I worked as hard as I could." The items of this scale had a high internal consistency (α = .93). More details of the questionnaire items are provided in Appendix A3.

4.2.3 Statistical Analyses

As described previously, three constructs were chosen (prior knowledge in mathematics, intrinsic motivation, and academic self-concept in math) to represent the individual learning prerequisites. Student involvement was captured by two constructs (situational interest and cognitive engagement). Except for prior knowledge, which was an observed variable, other study constructs were not directly observable and were indicated by multiple questionnaire items. In this situation, analyses were conducted to gather information about the latent constructs through the observable indicators, and then estimate the relationships between constructs. As recommended by Baron and Kenny (1986), to avoid the potential measurement errors shared across different observed variables (i.e., multiple regression models), structural equation modeling (SEM) is an appropriate statistical modeling technique to analyze the hypothesized relationships addressed in RQ1 and RQ2.

Linear Regression Models. To investigate the effects of individual learning prerequisites on student involvement in learning processes (RQ1), we ran separate regression models (see Appendix B1) for the two constructs of student involvement (i.e., situational interest and cognitive engagement). In each regression model, prior knowledge, intrinsic motivation, and academic self-concepts were treated as the predictor variables in the analyses. In the first regression model, we analyzed the effect of multiple predictor variables on the situational interest. Later, in the second regression model, cognitive engagement was regressed on those three learning prerequisites. During the analyses, the significance level in hypothesis tests was set at the .05 level. Also, the estimations of the regression models were based on the standardized regression coefficients (Wen et al., 2010).

Moderation. To answer the question of *when* (i.e., in which condition) the effect of individual learning prerequisites on student involvement changes (RQ2), we conducted separate moderation analyses for the outcome variables (Y), which consisted of two constructs (situational interest and cognitive engagement). Analytically, to discover whether the use of tablet computers (M) affects the strength of the relationship between individual learning prerequisites (X) and student involvement (Y), we tested the interaction between M and X in a model of Y (Baron & Kenny, 1986). In these measurement models, the predictors and outcome variables were continuous latent variables that inferred multiple indicators. More importantly, the moderator was a dichotomy variable, which indicated whether the students had worked with tablet computers (1 = tablet group) or not (0 = non-tablet group).

Based on this situation, multiple-group SEM is an appropriate analytical approach to test the difference in regression coefficients between latent variables (Marsh et al., 2013). Specifically speaking, the categorical moderator (i.e., $M_C = 0$, $M_T = 1$) was treated as two separate groups within each latent interaction model. That is, when the dichotomous moderator variable was kept consistent in each of the two regression models, we then tested whether the difference between the two regression coefficients relating to X and Y was significant.

However, the significant between-group difference from the previous step was insufficient to indicate an interaction effect in the multiple-group SEM. The difference in the regression weight was calculated based on the unstandardized regression coefficients in each group (Aiken et al., 1991; Marsh et al., 2013). To compute the standardized between-group difference relating to the predictor variable and outcome variable, the second step was to constrain the overall variance (i.e., the overall variance of the predictor variable and the overall variance of the outcome variable) across the tablet and non-tablet groups to 1.0. With these constraints, we were able to compute the standardized interaction effect represented by the differences between the standardized regression coefficients from the two separate groups.

Third, the measurement invariance between the two groups was examined in advance to the analyzing processes (Meredith, 1993; Meredith & Teresi, 2006). The strong measurement invariances for predictor variables and outcome variables were expected to be established (i.e., same factor loading and intercepts for each manifest items). Since the predictor and outcome variables of the current study did not have a meaningful zero point, the estimations of latent interactions in SEM were based on the standardized regression coefficients (Wen et al., 2010). Two-tailed statistical significance tests were conducted at the 5% level. In the current study, the latent interactions and regression analyses were conducted using the Mplus 8.0 software program (Geiser, 2013; Muthén & Muthén, 2017).

The Goodness of Model Fit. To find out to what extent the hypothesized SEMs fit the empirical student data, we conducted the chi-square goodness of fit test. Additionally, we examined the comparative fit index (CFI), the standardized root-mean-square residual (SRMR), and the root-mean-square error of approximation (RMSEA) to evaluate the appropriateness of the specified models. The cutoff criteria for these fitness indexes were based on Hu and Bentler's (1999) suggestion. A good fit is indicated by indices not smaller than .90 for the CFI and not larger than .05 for the RMSEA and SRMR.

Cluster Structure and Missing Values. Since students from the same class are not independent of each other, a cluster structure to nest the individual student at a class level was needed in the current study (Raudenbush & Bryk, 2002). To avoid the bias that results from the intraclass correlations, the individual values of each variable were clustered at the class level (*Cluster = Class, type = complex*) in the nested data structure (Geiser, 2013). Additionally, during the data collection procedure, most of the missingness was caused by item nonresponses (e.g., the participants skipped some items or did not know how to respond). To solve this incomplete-data problem, we used the modern procedure to minimize the estimation bias caused by missing at random (MAR) data (Schafer & Graham, 2002). Specifically, we chose the full information maximum likelihood (FIML) method, which included every piece of information in the analysis models (Newman, 2003). The FIML estimations were run in the Mplus, version 8.0 software program (Ender & Bandalos, 2001).

4.4 Results

Correlations and Descriptive Statistics

The primary goal of the current study was to examine the relationship between individual learning prerequisites and student involvement in mathematics learning and whether the tablet use moderated the relationship. Examining the intercorrelations between the study variables was the basis of the subsequent regression analyses. Table 4.1 presents a correlation matrix for the key constructs of the current study. It shows that the three constructs of the individual learning prerequisites were significantly correlated with students' situational interest. Each construct of the learning prerequisites also significantly and positively correlated with students' cognitive engagement in mathematics classes. Furthermore, regarding the descriptive statistics of the key constructs, Table 4.2 presents the means, standard deviations, and ranges of each study variable for the tablet and non-tablet class conditions.

Table 4.1

Intercorrelations of Study Variables

Construct	1	2	3	4	5
1. Math prior knowledge	—				
2. Intrinsic motivation in math	.33**	—			
3. Math self-concept	.28**	.75**	—		
4. Situational interest in math	.17*	.63**	.49**	—	
5. Cognitive engagement in math	.13*	.48**	.41**	.63**	—

Note. All the correlation coefficients are standardized.

*$p < .05$, 2-tailed. **$p < .01$, 2-tailed.

Table 4.2

Descriptive Statistics of Study Variables

Variable	Non-tablet class			Tablet class		
	M	*SD*	*Min/Max*	*M*	*SD*	*Min/Max*
Learning prerequisites						
Prior knowledge in math[a]	23.33	7.32	3/46	21.64	7.14	4/48
Intrinsic motivation	2.55	0.96	1/4	2.88	0.92	1/4
Math self-concept	2.64	0.68	1/4	2.89	0.73	1/4
Student involvement						
Situational interest	2.39	0.98	1/4	2.89	0.90	1/4
Cognitive engagement	2.90	0.88	1/4	3.11	0.84	1/4

Note. Sample of non-tablet class condition n = 1,017; sample of tablet class condition n = 1,089. The study variables were measured using a 4-point Likert scale ranging from 1 (*does not apply at all*) to 4 (*totally applies*).
[a] Prior knowledge in math was assessed using a standardized test (i.e., the KRW), which contained 57 questions. The total score ranged from 0 to 57.

RQ1: The Influences of Learning Prerequisites on Student Involvement

In the present study, since the student involvement consisted of two main constructs (situational interest and cognitive engagement), we conducted separate linear regression analyses. Both analyses involved multiple individual learning prerequisites as the predictor variables. In the first model, we regressed situational interest on three learning prerequisites (prior knowledge in math, intrinsic motivation in math, and math self-concept).

For the first regression model, the goodness of fit indices showed that the model with situational interest as the dependent variable had a good model fit: $\chi^2 = 878.71$, $df = 60$, $p < .001$; SRMR = .05; RMSEA = .07, 95% CI [.07, .08]; and CFI = .95. Moreover, the results of the first regression model indicated that students' prior mathematics knowledge was significantly predictive of higher situational interest in math classes: $\beta = .21$, $SE = .10$, 95% CI [.09, .23], $p = .02$. From this standardized regression coefficient, we determined that adequate prior mathematics knowledge predicted a higher level of situational interest. Regarding the second learning prerequisite construct, the results pointed out that students' intrinsic motivation in math significantly and positively predicted their situational interest: $\beta = .53$, $SE = .03$, 95% CI [.50, .63], $p < .001$. The significant standardized regression coefficient was consistent with our expectation that students' intrinsic motivation positively predicts greater situational interest in math classes. Furthermore, the results also indicated that the effect of students' math self-concept on situational interest was statistically significant ($\beta = .04$, *SE* = .03, 95% CI [.03, .15], $p < .01$). This finding was consistent with the hypothesis that students' academic self-concept in math was a positive predictor of their situational interest in mathematics classrooms.

In the second linear regression model, the dependent variable was the students' cognitive engagement in mathematics classes. The goodness-of-fit indices showed a good model fit: $\chi^2 = 982.80$, $df = 39$, $p < .001$; SRMR = .06; RMSEA = .09, 95% CI [.09, .10]; and CFI = .90. Building on the adequate fitness, the results revealed that students' prior mathematics knowledge positively predicted on cognitive engagement in mathematics classes: $\beta = .63$, *SE* = .07, 95% CI [.49, .77], $p < .001$. The finding implied that higher prior mathematics knowledge predicted a greater level of cognitive engagement. For the second predictor variable, the results showed that students' intrinsic motivation in mathematics significantly and positively predicted their cognitive engagement: $\beta = .39$, *SE* = .02, 95% CI [.31, .40], $p < .001$. Based on the finding, we determined that students with higher intrinsic motivation seem to show greater cognitive engagement in mathematics classes. Furthermore, regarding the last individual learning prerequisite, the findings showed that students' academic self-concept in math significantly impacted their cognitive engagement in mathematics: $\beta = .09$, *SE* = .03, 95% CI [.04, .16], $p < .001$. In other words, students who had high math self-concept were more cognitively engaged in mathematics classes.

The above findings were consistent with our expectations regarding the effect of individual learning prerequisites. The results confirmed that the three individual learning prerequisites were positive predictors of students' situational interest and cognitive engagement in mathematics learning.

RQ2: The Use of Tablet Computers as Moderator

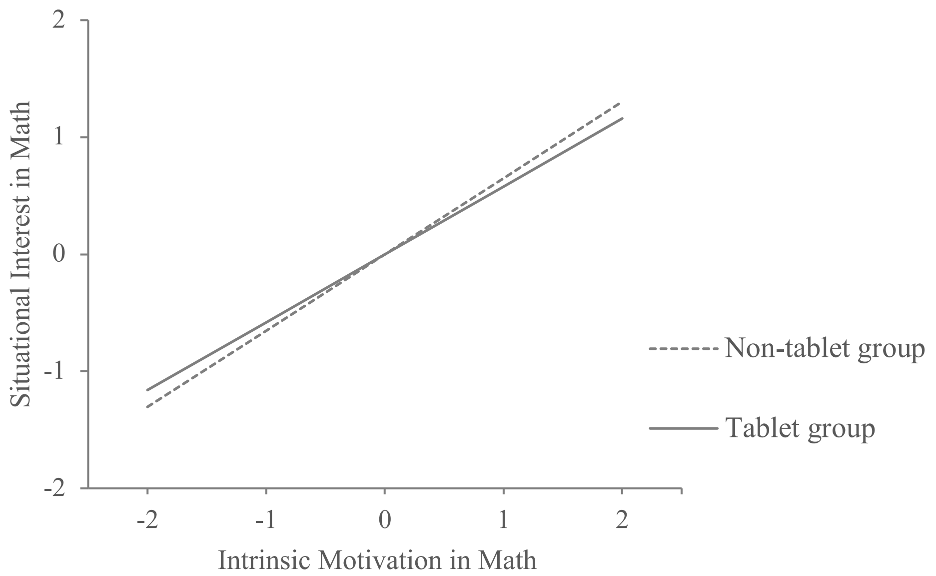
In the current study, student involvement consisted of two constructs. To test whether the effect of individual learning prerequisites on student involvement depends on the use of tablet computers (RQ2), we conducted separate latent interaction analyses (i.e., multiple-group SEM). The first part of this research question investigated the moderation effect of using tablet computers on the effect of learning prerequisites on students' situational interest.

First, the result indicated a good model fit of the simple linear regression models of the multiple-group SEM regarding intrinsic motivation and situational interest: $\chi^2 = 10656.34$, $df = 56$, $p < .001$; SRMR = .02; RMSEA = .04, 95% CI [.03, .04]; and CFI = .99. Based on this model, the results indicated that intrinsic motivation had a significant influence on situational interest in both the non-tablet group ($\beta_{yx|0}$ = .65, *SE* = .02, 95% CI [.60, .70], $p < .001$) and tablet group condition ($\beta_{yx|1}$ = .58, *SE* = .03, 95% CI [.52, .64], $p < .001$). Therefore, high intrinsic motivation for both groups of students was predictive of high situational interest in mathematics classes.

The regression lines of the two conditions were plotted in Figure 4.2. In the tablet group, the positive regression slop was slightly smaller than the slop in the non-tablet group. In other words, it is reasonable to interpret that under the tablet class condition (M_T = 1), the change in situational interest associated with a 1-unit of intrinsic motivation is smaller than the ones in the non-tablet class condition (M_c = 0). Thus, the use of tablet computers significantly moderated the relationship between intrinsic motivation and situational interest in mathematics classes.

Figure 4.2

Interaction Effect of Using Tablets on the Relationship Between Intrinsic Motivation and Situational Interest



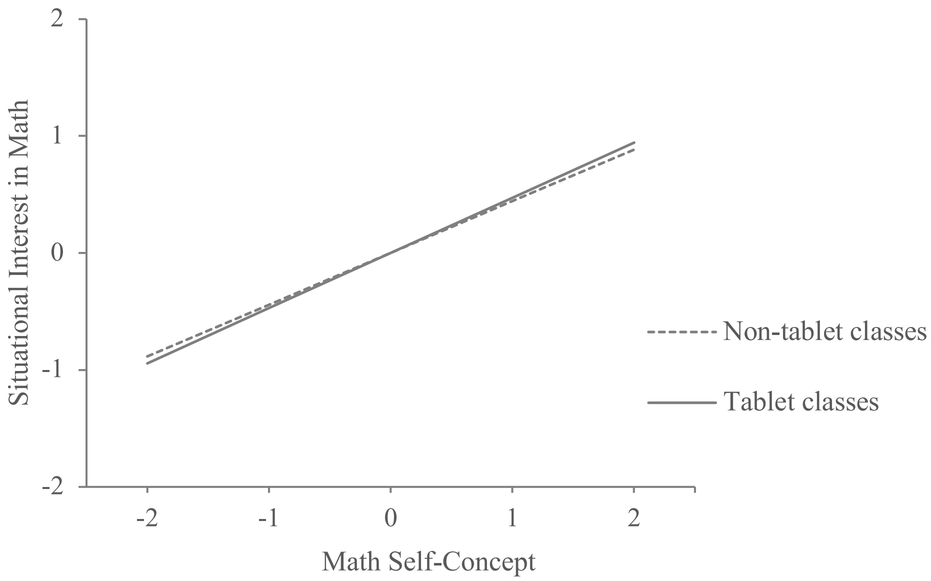
Note. This graph demonstrates two regression slopes, in which situational interest was regressed on intrinsic motivation. This graphical representation was based on the standardized scores in the regression equation. The dichotomous moderator is the use of tablet computers (0 = non-tablet group, 1 = tablet group).

Additionally, to compare the corresponding effects between the two groups, the overall variance in intrinsic motivation and situational interest was constrained across the two groups. Based on the constrained model, the results indicated that the effect of intrinsic motivation and situational interest was significantly different between the tablet and non-tablet class conditions (β = -.09, *SE* = .04, 95% CI [-.17, .00], $p = .05$). The results of the constrained model found that the interaction effect explains a significant amount of the variance in students' situational interest (β_{yx} = -.09, *SE* = .04, 95% CI [-.17, .00], p = .05; across group R^2 = .41, $p < .001$). In other words, for the tablet group, the impact of intrinsic motivation on situational interest was smaller than the non-tablet group; and statistically, the interaction effect accounted for 41% of the variation in situational interest. Therefore, the findings were consistent with our expectation that the use of tablet computers in mathematics classes significantly moderates the relationship between students' intrinsic motivation and situational interest.

Moreover, the results of the second multiple-group SEM indicated that math self-concept significantly predicted situational interest in both the non-tablet group ($\beta_{yx|0}$ = .44, *SE* = .03, 95% CI [.37, .59], $p < .001$) and the tablet group ($\beta_{yx|1}$ = .47, *SE* = .03, 95% CI [.39, .55], $p < .001$). Based on this finding, the regression lines of two groups were plotted in Figure 4.3. The positive regression slope of the tablet group was slightly steeper than that of the non-tablet group. However, the results of the multiple-group SEM did not identify a significant difference between the two groups. Thus, the use of tablet computers did not significantly moderate the relationship between math self-concept and situational interest in mathematics classes.

Figure 4.3

Interaction Effect of Using Tablet on the Relationship Between Math Self-Concept and Situational Interest



Note. This graph demonstrates two regression slops, in which situational interest was regressed on math self-concept. This graphical representation was based on the standardized scores in the regression equation. The dichotomous moderator is the use of tablet computers (0 = non-tablet group, 1 = tablet group).

Nevertheless, regarding the third individual learning prerequisite, the results of the multiple-group SEM relating prior mathematics knowledge to situational interest did not show a significant difference between the tablet and non-tablet class conditions. Therefore, the use of tablet computers in mathematics classes did not significantly moderate the relationship between students' prior knowledge and situation interest in mathematics learning.

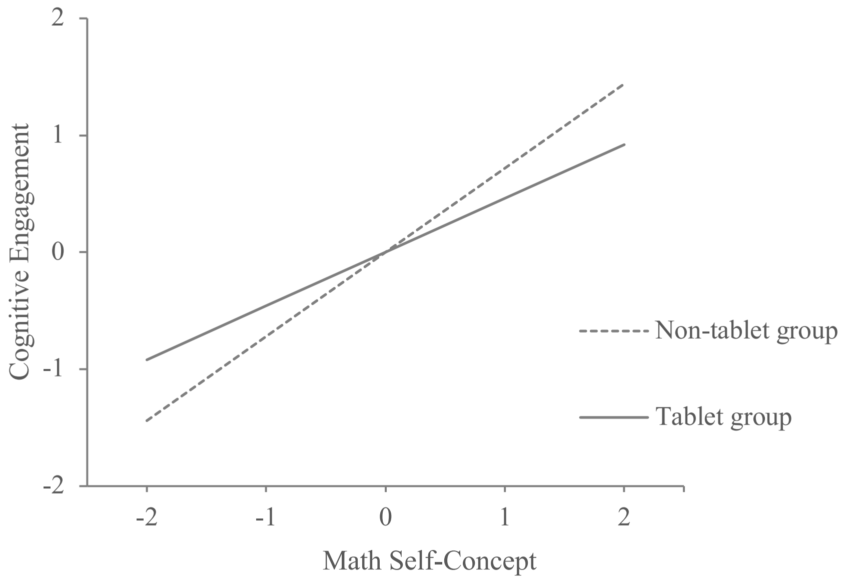
Since two constructs captured the student involvement in mathematics learning, the second part of RQ2 investigated the moderating effects of using tablet computers on the relationship between individual learning prerequisites and cognitive engagement in mathematics learning. Regarding the effect of intrinsic motivation on cognitive engagement, the results indicated a significant standardized regression in both the non-tablet group ($\beta_{yx|0}$ = .48, *SE* = .03, 95% CI [.42, .54], $p < .001$) and the tablet group ($\beta_{yx|1}$ = .47, *SE* = .03, 95% CI [.40, .53], $p < .001$). Nevertheless, after comparing the two regression coefficients, the results did not find a significant difference between the tablet and non-tablet groups (p = .96). Therefore, the use of tablet computers did not significantly moderate the relationship between students' intrinsic motivation and cognitive engagement in mathematics classes.

Furthermore, the results indicated that math self-concept significantly predicted the students' cognitive engagement in both the non-tablet group ($\beta_{yx|0}$ = .72, *SE* = .02, 95% CI [.58, .73], $p < .001$) and the tablet group ($\beta_{yx|1}$ = .46, *SE* = .04, 95% CI [.39, .74], $p < .001$). The regression lines of the two groups are depicted in Figure 4.4. The regression slope of the non-tablet group is steeper than that of the tablet group. Therefore, under the tablet class condition ($M_T = 1$), the change in math self-concept associated with a 1-unit increase in cognitive engagement is smaller than under the non-tablet class condition ($M_c = 0$).

Figure 4.4

Interaction Effect of Using Tablet on the Relationship Between Math Self-Concept and Cognitive Engagement

Note. This graph demonstrates two regression lines, in which cognitive engagement was regressed on math self-



concept. This graphical representation was based on the standardized scores in the regression equation. The dichotomous moderator is the use of tablet computers (0 = non-tablet group, 1 = tablet group).

More importantly, the results revealed that the regression coefficients in relating math self-concept to situational interest were statistically different between the two groups (β_{yx} = -.18, *SE* = .06, 95% CI [-.30, -.06], $p = .05$; $\Delta R^2 = .61$, $p < .001$). In other words, for those students in tablet group, the impact of their math self-concept on cognitive engagement was smaller than the non-tablet group. Thus, the use of tablet computers significantly moderated the relationship between math self-concept and cognitive engagement in mathematics classes. Finally, when looking at the moderation effect between the prior mathematics knowledge and cognitive engagement in mathematic learning, the results did not show a significant interaction.

4.5 Summary

The purpose of this study was to investigate the effect of motivational and cognitive learning prerequisites on student involvement in learning processes, as well as whether these relationships were moderated by the integration of tablet computers in mathematics classrooms. The empirical findings confirmed the first research question, which hypothesized that individual learning prerequisites (operationally defined as a collection of three student characteristics in this study) significantly influence student involvement in learning processes.

In particular, students' prior mathematics knowledge, intrinsic motivation, and math self-concept were positive predictors of two aspects of student involvement in mathematics learning processes: (a) situational interest and (b) cognitive engagement. These positive influences were found in both tablet and non-tablet classes. Therefore, individual students vary in their learning prerequisites, and these differences account for the effectiveness of learning opportunities during instructions. The findings of the present study provide empirical support to the conjectures derived from the supply-use model. Additionally, the results align with the earlier research, which identified the domain-specific prior knowledge as a reliable predictor of student learning (Dochy et al., 2002).

The second research question examined in which condition the effect of individual learning prerequisites changes. When we further explored the interaction effect between particular learning prerequisites and the use of tablet computers in mathematics classes, we found that in the tablet class condition, the magnitude of the effect of intrinsic motivation on students' situational interest is smaller than under the non-tablet class condition. A similar effect was found in cognitive engagement: under the tablet class condition, the effect of math self-concept on students' cognitive engagement decreases. These findings of interaction effects were in line with our expectations.

However, the moderation effect does not occur in the relationship between the other two aspects of learning prerequisites (prior mathematics knowledge and math self-concept) and situational interest. Additionally, we also did not find empirical evidence of the interaction between prior mathematics knowledge and the use of tablets on students' cognitive engagement. The results of the nonsignificant interaction effect contradict our hypothesis. The possible explanation of the nonsignificant moderation effect between the prior mathematics knowledge and two constructs of student involvement (indicated by situational interest and cognitive engagement) in mathematics learning may be due to the measurement of students' mathematics competence. In the present study, the prior knowledge was assessed by the calculation items (i.e., KRW test) which covered the topic of algebra. However, the students' procedural knowledge of knowing the steps of solving the mathematics problems (i.e., know-how) were not tested during the study. Therefore, it is the fact that the findings did not provide a comprehensive picture of the students' mathematics competence that hindered the investigation of its relationship with using tablet computers and engagement during the mathematics learning processes. More limitations and implications of the current study and the future perspective are discussed in Chapter 7.

5

ICT-Based Instruction: Latent Changes in Student Involvement in Mathematics Learning

This chapter described *Study 2* and reported the method and results in detail. In this chapter, part of the reporting information overlaps with the manuscript [1]. Shared aspects: (1) Research focus, but the manuscript additionally focused on the use of technology in the German as language classrooms; (2) Using data from the research project *tabletBW meets science*; (3) The statistical analyses were based on the same sample and measurement waves; (4) Variables: Frequency of using tablet computers, tablet related learning activities, and cognitive engagement. Therefore, the plural form of the first person "we" was used to address team effort. But the body of the chapter was written by the sole author.

[a] Fütterer, T., Cheng, X., Scheiter, K., & Stürmer, K. (2020). Quality beats quantity: Investigating students' effort in learning when introducing technology in classrooms. Manuscript submitted to the *Journal of Educational Psychology*. The manuscript has not been accepted and published yet.

Chapter 5 ICT-Based Instruction: Latent Changes in Student Involvement in Mathematics Learning

This chapter describes the second empirical study (*Study 2*) of the dissertation. According to the empirical findings from the previous chapter, the use of tablet computers in mathematics classes was found to significantly weakened the effect of some individual learning prerequisites on student involvement in learning processes. Based on the findings, this chapter focuses on whether the positive effect of using tablet computers on students' active involvement would persist for more extended periods. Additionally, the present chapter took a closer look at the mechanism that contributes to the more effective integration of tablet computers in mathematics classrooms. Through examining the quantity and quality of integration, the study of the presented chapter provided an insight into the consistency of the effect of using tablets on student involvement in learning mathematics.

5.1 The Present Study

Recent advances in integrating educational technology in school settings provide students with more opportunities to learn and bring tangible changes to current teaching (Cheung & Slavin, 2013). Along with the growth in the use of technology, there is increasing concern over the effect of ICT-based instruction on students' learning processes. Even though many researchers pointed out that students tend to learn better while working with technology such as computers, teachers are still struggling in providing effective integration of technology (Kulik, 2002). The problem is not from the digital devices per se, but rather it is how to use the tools properly. Without an appropriate introduction and effective implementation, technology cannot imply meaningful learning opportunities and support student learning in classrooms (Clark, 1983; Nathan & Robinson, 2001). Hence, the utilization of technology requires careful and gradual adoption. Which components of the integration determine its consequence for student learning? Does the integration of technology affect learning in the long term? More research needs to be conducted to answer these questions and examine further how technology is used for educational purposes. However, since the integration of technology varies a great deal, it is challenging to observe and evaluate its use in classrooms.

Previous studies have attempted to clarify the relationship between technology use (e.g., quality and quantity of integration) and students' learning processes (Zhai et al., 2016). Some of them have conducted classroom-based interventions to study the effect of the teaching process on students' cognitive engagement. For instance, using data from fourth-grade teachers, Swing et al. (1988) compared two teaching conditions: In the learning-time intervention group, the teachers increased their academic learning time (quantity). In the thinking-skills intervention group, the teachers used cognitive strategies to facilitate higher-order learning (quality). The study found that the students in the latter group showed a higher level of cognitive engagement in mathematics learning. Recent studies have also found a positive relationship between innovative technology integration and student engagement (Han & Finkelstein, 2013a; Pellas, 2014). On the basis of past research, it is reasonable to assume that the use of technology needs to have the aspects of both quality and quantity to offer effective integration, and perhaps the quality of integration is even more critical.

In the present study, the frequency of using tablet computers was treated as an observable variable to indicate the integration quality. This indicator of integration quality was based on Puentedura's SAMR model (2010), which divided the use of technology into four categories: substitution, augmentation, modification, and redefinition. According to the SAMR, the implementation of technology corresponds to different levels of learning tasks that allow for various changes in traditional instruction. During mathematics classes, students sometimes have no sufficient strategies to solve the real-world mathematics problem. In response to the learning needs, the use of computers (e.g., simulation games) for problem-solving simulation enables the students to engage in discovery processes (Liu et al., 2011). This type of technology-related is innovative and difficult to be replaced by the traditional teaching approach (De Jong, 1991). Therefore, simulation type of classroom activity is a good practice of the transformation use of technology in mathematics classes (Puentedura, 2003).

Apart from the uncertainty of integrating technology, another issue of technology-based education is the inconsistent findings of the impact of ICT-integration (Chu, 2014). Some researchers criticized the effectiveness of technology in mathematics learning (Campuzano et al., 2009). One possibility is that only a few intervention studies have been conducted in real school settings to examine how teachers and students worked with ICT in the classrooms. Research investigating the connection between technology and education comprises the diverse design and implementation approaches. In addition, many recent studies did not use an experimental setting. They were thus unable to include a non-tablet group (e.g., no access to tablet computers in classes) for comparison. Also, a large number of ICT-related empirical studies had only a brief duration, which was commonly less than 12 weeks (Kulik & Kulik, 1991). Furthermore, many previous studies used only a posttest design, which made it impossible to examine changes in student learning.

Thus, the present study was longitudinal, used the popular one-to-one mobile devices of ICT (i.e., tablet computers), and investigated its implementation in real mathematics classrooms. The present study aimed to uncover changes in learning responses that students exhibited between two time periods as a function of ICT-based instruction. Moreover, in light of previous considerations with respect to how to effectively integrate technology in the mathematics classroom, the quantity and quality of the integration are crucial. Therefore, two critical questions about the effect of the use of tablet computers on student involvement in mathematics learning were addressed in the present study

5.2 Research Questions

Based on the preceding review of the literature, the present study focused on student involvement in learning from two aspects: motivational involvement and cognitive involvement. An initial research question served to investigate the effect of the technology integration on longitudinal changes in two aspects of student involvement during mathematics learning processes.

RQ1: Is the use of tablet computers in mathematic classes associated with changes in student involvement in mathematics learning over time?

Since the relationship between the use of tablet computers and its prolonged impact on student learning is less clear, the first research question attempted to explore whether the consistent effect of using tablet computers appeared in seventh-graders' situational interest and cognitive engagement. Specifically speaking, we hypothesized that compared with the regular classroom condition, the students in the tablet group had a slower decline in their average levels of situational interest and cognitive engagement over time.

Building on the first research question, a new question raised: How does the use of tablet computers make a difference in the changes in student involvement in mathematics learning over time? In attempting to understand the mechanism (i.e., how) behind the integration of tablet computers, the next research question was to take an in-depth look at the quantity of tablet integration and its influence on students' changes situational interest and cognitive engagement in mathematics classes.

RQ2: Are the changes in student involvement in mathematics learning associated with the quantity of using tablet computers in the classrooms?

Regarding the indicator of the quantity of technology integration, we hypothesized that the higher the frequency of use, the more substantial the increase in students' situational interest and cognitive engagement over time. On the other hand, we expected that compared with the replacement type of tablet-related classroom activities, the elaborative activities would bring about a more substantial increase in students' situational and cognitive engagement in the long term.

Finally, if, as indicated in the previous literature, the quality of implementation was more important than the using frequency for student learning processes (Lei, 2010), the mechanism of tablet integration needed to be further explored. The last research question was posed to address the effect of the different types of tablet use for supporting particular classroom activities on student involvement in learning processes. The type of tablet-related activities was categorized and assessed in two aspects: use for enhancement and use for transformation.

RQ3: Are the changes in student involvement in mathematics learning associated with the quality of using tablet computers in the classrooms?

5.3 Method

5.3.1 Sample and Procedure

The current study used longitudinal student data drawn from the *tabletBW* research project. For the purpose of this study, students in Cohort 1 were selected as the sample, and the analyses covered three measurement points. A sample of 1,363 seventh graders (50% female adolescents) from twenty-eight upper secondary schools in southern Germany participated in the study. These participants were assigned to the non-tablet class condition (n = 689) and the tablet class condition (n = 674). Specifically, at the baseline measurement point (t_{10}), the participants were between 12 and 18 years old (M = 13.35, SD = 0.56). At the third measurement point (t_{12}), which took place 16 months after the initial assessment, these students turned into eighth graders between 13 and 19 years old (M = 14.31, SD = 0.55). At t_{12}, due to the schools' decisions, there were eight control schools dropped out, and thus, there remained only six of them continuously participated in the study.

As previously indicated in the general method and project overview, tablet computers were introduced into tablet classes after the baseline measurement (t_{10}). Later, the second measurement (t_{11}) took place four months after the initial measurement point, and the third measurement point took place 12 months after the previous one.

5.3.2 Measures

Integration of Tablet Computers. In the current study, we assessed how the tablet computers were implemented in mathematics classes from two dimensions: (a) quantity and (b) quality of integration. The mechanisms behind the integration of technology were treated as the predictor variables of the changes in student involvement in learning processes. In the questionnaire, students in the tablet classes were asked to respond to the statements based on their experiences of using tablet computers in the past four (t_{11}) or twelve (t_{12}) months in mathematics classes.

Quantity of using tablet computers was treated as the first mechanism to explain the integration of technology in classrooms**.** We used the frequency of tablet use during the semester to indicate the quantity of technology integration in mathematics classes. Via self-reports, the students in the tablet group were asked to recall and report how frequently they had used their tablet computers in mathematics classes on a scale ranging from 1 to 20 times. At the measurement point t_{11}, the students rated the frequency of use for the previous four months (e.g., "How often did you work with the tablet in mathematics this semester"). After 12 months at t_{12}, the using frequency was assessed again for the previous school year.

Quality of using tablet computers was the other mechanism to explain how students worked with tablet computers in classrooms. To assess the quality of the integration in the mathematics instructions, we selected 18 types of tablet-related classroom activities (e.g., reading the digital textbook, doing calculations, doing homework). We examined how technology was used to engage in these activities by asking the tablet class students' relevant learning experience ("If you worked with the tablet computer, did you use it for [a particular classroom activity]?" The respondents indicated their agreement on a 4-point Likert scale that ranged from 1 (*does not apply at all*) to 4 (*totally applies*). According to the SAMR model, we classified the classroom learning activities into two dimensions: enhancement and transformation (Puentedura, 2003). For instance, based on the characteristics and potentials, the use of tablet computers for *simulation* was treated as a transformative type of learning activity. Using this two-dimensional classification, we recoded the students' responses into a dichotomous variable: 0 (*not used*) and 1 (*used*). The next step was to conduct the separated regression models for the difference between the means of two dependent variables, which were regressed on the enhancement and transformation types of classroom activities.

Table 5.1

Tablet-Related Classroom Activities Regarding the Types of Enhancement and Transformation

SAMR dimension	Tablet-related classroom activity
Enhancement	During the mathematics classes, we worked with tablet computers …
	… to calculate or work with databases.
	… do individual homework.
Transformation	During the mathematics classes, we worked with tablet computers …
	… to work with a learning program.
	… to conduct a simulation.

Note. The students' responses to the four-point Likert scale were recoded into a dummy variable.

Student Involvement in Learning Processes. In the present study, student involvement in learning processes was measured with the student-report questionnaire. For the instruments prepared for non-tablet class or tablet class conditions, we used parallel wording to structure all questionnaire items. The participants rated their perceived engagement with scales ranging from 1 (*does not at all apply*) to 4 (*totally applies*). These two aspects of students' responses were repletely assessed by identical student questionnaire items at three measurement points.

Situational Interest, as a motivational aspect of student involvement, refers to a person's temporary state of interest in a task or learning activity. To assess students' perceptions of their situational interest, the five-item scale was modified to apply to a math context. The selected items had been successfully applied in other published studies that evaluated students' motivational responses to learning tasks (Knogler et al., 2015). The respondents rated the extent to which each of the five items applied to their classroom experiences (e.g., "In the mathematics classes, the teaching captured my attention"). The situational interest scale had a high internal consistency across measurement points (reliability coefficient α ranged from .81 to .95). The content of the rating scale items is shown in Appendix A3.

Cognitive Engagement, as the other aspect of student involvement, refers to a person's investment of mental effort in understanding concepts or solving learning tasks. We measured students' cognitive engagement in mathematics classes using four items (Rimm-Kaufman et al., 2015). The participants rated the degree to which they agreed with statements about the past learning experiences (e.g., "In the mathematics classes, I tried as hard as I could"). The internal consistency of four items across measurement points was high (α ranged from .81 to .95). The supplementary information of the questionnaire items is included in Appendix A3.

5.3.3 Statistical Analyses

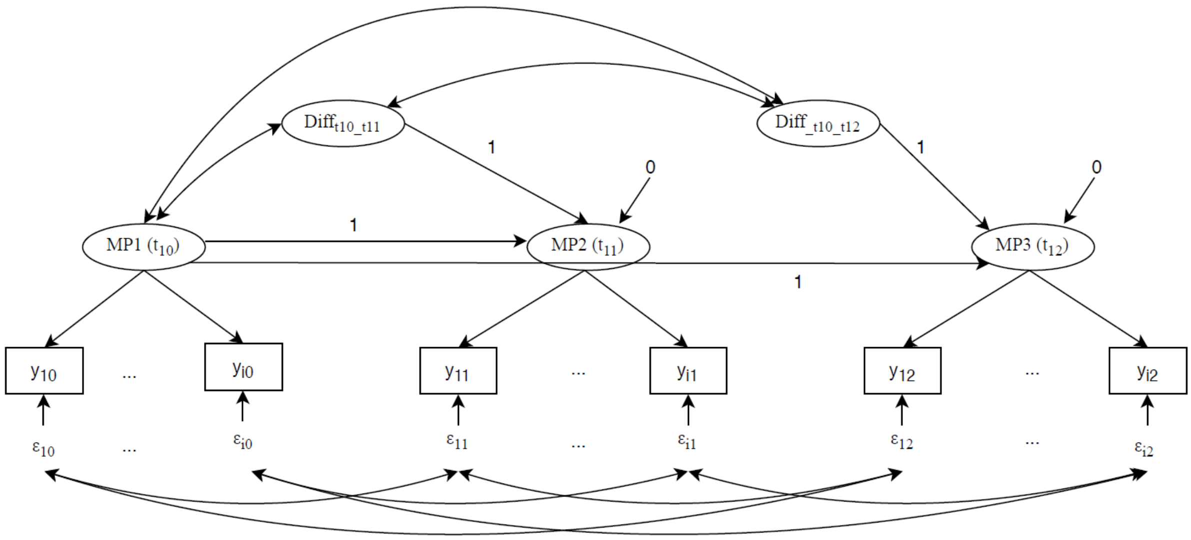
Baseline Latent Change Models. The present study primarily focused on whether the students in the tablet and non-tablet classes differ in their patterns of change in student involvement; and investigating the variables that predict these differences in change. To answer these questions, we need to conduct models of change. In this study, because both constructs of involvement were the latent variables measured by multiple questionnaire items, structural equation modeling (SEM) was an appropriate statistical technique to gather information through the observed variables. Meanwhile, in the study of longitudinal changes, we used the baseline latent change models (LCM) to analyze the hypothesized relationships between the integration of technology and the changes in student involvement across measurement points (McArdle & Hamagami, 2001).

To examine whether the latent changes in student involvement were different between the tablet and non-tablet class conditions (RQ1), we decomposed the statistical analyses into two steps. First, to assess the interindividual change scores of the first construct of involvement, we specified the LCM of situational interest (see Figure 5.1).

In the baseline measurement model, we separately calculated the difference of mean scores for situational interest in a short-term ($Diff_{t0t1}$= different score between t_{10} and t_{11}) and the long-term ($Diff_{t0t2}$= different score between t_{10} and t_{12}). With the calculated scores of latent differences, the second step was to conduct the multi-group LCMs to compare the short-term and long-term differences in situational interest between the tablet and non-tablet class conditions. During this process, the use of tablet computers in mathematics classes was represented by a dichotomous variable: 0 = did not work with tablet computers in mathematics classes (i.e., non-tablet class condition), and 1 = had used tablet (i.e., tablet class condition). In the multi-group LCMs, we controlled for the baseline differences as covariates (Geiser, 2013). Additionally, we tested the statistical power of the mean differences between the two conditions by using Cohen's *d* with polled standard deviation. Identical analytical processes were applied to the construct of cognitive engagement.

Figure 5.1

Baseline Latent Change Model

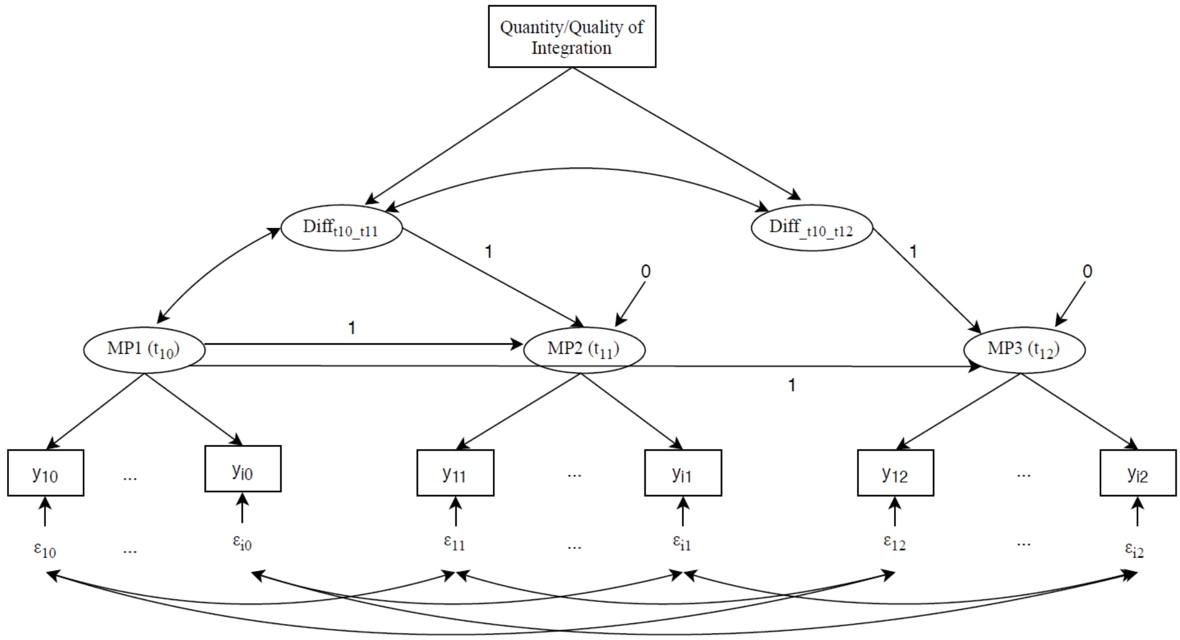


Note. This figure is the hypothesized baseline latent change model of RQ1. MP1 = latent variable (i.e., situational interest or cognitive engagement) at the first measurement point. MP2 = latent variable at the second measurement point. MP3 = latent variable at the third measurement point. $Diff_{t10\_t11}$ refers to the change in situational interest between measurement points t_{10} and t_{11}. y_{ij} = the j^{th} item at measurement point *i*. ε = error.

To test whether the changes in student involvement were associated with the mechanism of how the tablets were utilized (i.e., the quantity and quality of integration; RQ2 and RQ3), we ran separate LCMs for the two constructs of student involvement: a) situational interest and b) cognitive engagement accordingly (see Figure 5.2). During the process, the analyses involved the tablet group sample and excluded the non-tablet group students. Regarding the predictor variables of the latent change in situational interest or cognitive engagement, the quantity of integration was indicated by one manifest variable (i.e., Using frequency). For the indicator of integration quality in the classrooms, the analyses separately involve two indicators: a) enhancement type of use and b) transformation type of use.

Figure 5.2

Baseline Latent Change Model with Integration Mechanism as Predictor



Note. This figure is the hypothesized baseline latent change model of RQ2 and RQ3. MP1 = latent variable (i.e., situational interest or cognitive engagement) at the first measurement point. MP2 = latent variable at the second measurement point. MP3 = latent variable at the third measurement point. $Diff_{t10\_t11}$ refers to the change in situational interest between measurement points t_{10} and t_{11}. y_{ij} = the j^{th} item at measurement point *i*. ε = error.

In the baseline LCM, the using frequency was treated as a predictor in a linear regression model to uncover whether the quantity of tablet-based instruction influence the changes in students' active learning processes. Based on this measurement model, we calculated the differences in the latent means of situational interest/cognitive engagement between measurement points. Finally, the latent mean differences were regressed on the frequency accordingly.

In addition to the quantity of integration, we also examined whether the quality of using tablet computers predicted changes in student involvement in mathematics instruction. As noted earlier, in the current study, the specific tablet-related classroom activities were categorized into two dimensions: enhancement and transformation type of use. After grouping the activities, the original Likert-type responses of the classroom activities were recoded into as the dichotomous variable (0 = did not work with tablets in the particular activity, 1 = worked with tablets in the particular activity). These dichotomous variables were treated as the predictors of the LCM. The estimations of baseline latent change in SEM were based on the standardized regression coefficients (Wen et al., 2010). All the LCM analyses were conducted in the Mplus 8.0 statistical software (Muthén & Muthén, 2017). All significance level in the hypothesis test was performed at .05 level.

Measurement Invariance. When analyzing longitudinal data, to assess whether the students' responses to the same items were stable over time, the present study tested the stability of the latent outcome variables across three measurement points. Suggested by Widaman and Reise (1997), the configural, metric, and scalar invariance were tested to ensure that the models, factor loadings, and intercepts had consistent units between groups. In order to obtain the equivalence of the constructs between the two conditions and across time, the scalar (strong) measurement invariances (i.e., same factor loading and intercepts for each manifest items) for predictor variables and outcome variables were expected to established (Meredith, 1993; Meredith & Teresi, 2006). The evaluation of model fit indexes was based on the recommendation from Cheung and Rensvold (2002).

Cluster Sampling. Since students from the same class are not independent of each other, a cluster structure to nest the individual student at a class level was needed. To avoid the bias that results from the intraclass correlations (ICCs), we used the primary sampling units, and the individual values of each variable were clustered at the class level (*Cluster* = *Class, type* = *complex*) in the nested data structure (Geiser, 2013).

Handling Missing Values. Missing data is a common issue in educational research, primarily when the study involves students' self-report measures and conducting a multi-wave assessment (Allison, 2003; Graham, 2009). In the present study, the missingness resulted from two main reasons. On the one hand, the item nonresponse caused the incomplete data at the item level (e.g., respondents skipped items; respondents may not know how to answer). In this situation, since the probability of missing data was unrelated to any other measured variables, the values were missing completely at random (Rubin, 1976). On the other hand, the missingness was also due to wave nonresponse. As noted earlier, at measurement point t_{12}, eight out of 14 control schools made the internal decisions and dropped out of the study. Because this longitudinal attrition was unpredictable, the full information maximum likelihood (FIML) approach was applied and conducted in Mplus to deal with these missing responses (Graham, 2009; Newman, 2003; Schafer & Graham, 2002).

5.4 Results

Test for Measurement Invariance

The purpose of this study was to investigate whether the use of tablet computers enhanced student involvement in mathematics learning over time, and the mechanism of the integration of tablet computers in the classrooms. Before answering RQ1, the current study examined the measurement invariance and fit of the baseline latent change model across groups and three measurement points. Regarding the first latent change model, which analyzed the latent changes in students' situational interest, the loadings of each latent factor and the intercept of each individual manifest variables were held consistently. With this model constrain, the model fit indices showed a good model fit: $\chi^2 = 327.87$, $p < .001$; standardized root-mean-square residual (SRMR) = .04; root-mean-square error of approximation (RMSEA) = .03, 95% CI [.02, .03]; and comparative fit index (CFI) = .99.

Additionally, when we looked at the model-fit test of the second baseline latent change model, which examined the change in students' cognitive engagement over time, it also had a good model fit: $\chi^2 = 118.46$, $p < .001$; SRMR = .04; RMSEA = .03, 95% CI [.03, .04]; and CFI = .99. Hence, the construct of situational interest and cognitive engagement in the baseline latent change models had an equivalent meaning in the tablet and non-tablet groups and across the three measurement points.

RQ1: The Changes in Student Involvement

The first research question aimed to investigate the changes in two constructs of student involvement (i.e., situational interest and cognitive engagement) in mathematics learning across three measurement points and whether these changes were associated with the use of tablet computers in mathematics classrooms. The student situational interest and cognitive engagement were assessed repeatedly with identical questionnaires at each measurement point. Table 5.2 shows the descriptive statistics of the tablet and non-tablet classes. Generally, the students from the tablet class had higher mean values of situational interest than the students in the non-tablet class at each measurement point.

Additionally, the longitudinal changes in students' situational interest in the tablet and non-tablet groups were plotted (see Figure 5.3). The figure shows that in the non-tablet group, students' situational interest in mathematics classes decreased across the three measurement points. In contrast, for the students in the tablet group, their situational interest grew between the first (t_{10}) and second measurement points (t_{11}). However, starting from the second measurement point until the third measurement point (t_{12}), a decrease showed in the students' situational interest in the tablet group. Therefore, in the long term (between t_{10} and t_{12}; across 16 months), the declining trend was observed in both tablet and non-tablet groups.

Table 5.2

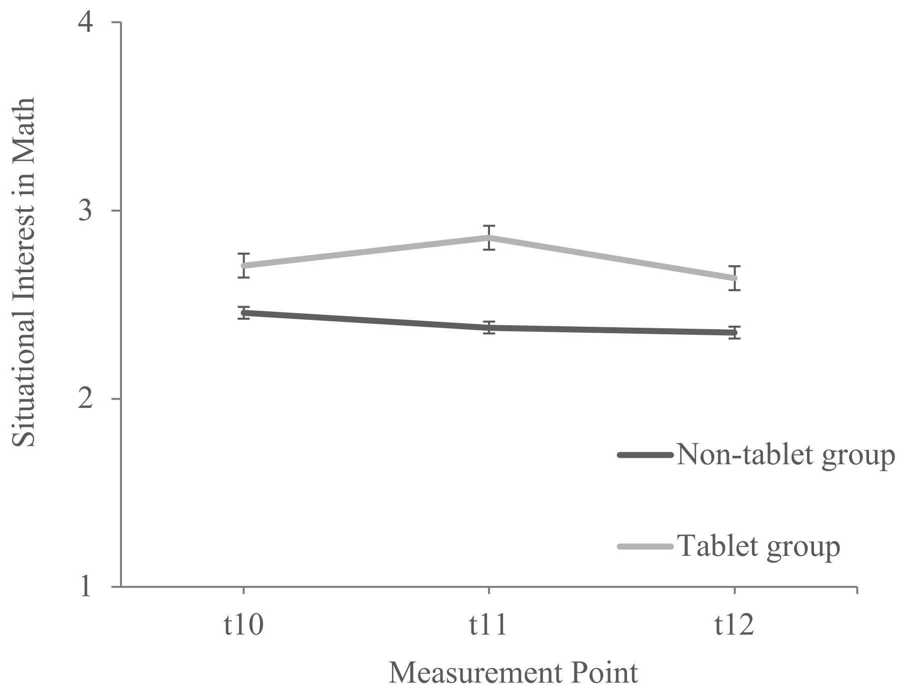
Descriptive Statistics of the Outcome Variables

Outcome variable	Condition	t_{10}		t_{11}		t_{12}	
		M	*SD*	*M*	*SD*	*M*	*SD*
Situational interest	Non-tablet class	2.46	0.91	2.38	0.98	2.36	0.96
	Tablet class	2.70	0.88	2.85	0.91	2.64	0.94
Cognitive engagement	Non-tablet class	3.02	0.69	2.80	0.87	2.70	0.90
	Tablet class	3.12	0.64	3.04	0.82	2.86	0.85

Note. Sample size of non-tablet class condition = 689; sample size of tablet class condition = 674. Situational interest and cognitive engagement were treated as two constructs of student involvement in learning processes.

Figure 5.3

Changes in Situational Interest Across Three Measurement Points



Note. This graph demonstrates the changes in students' situational interest in mathematics classes across three measurement points. t_{10} = first measurement point (baseline); t_{11} = second measurement point; t_{12} = third measurement point. Error bars represent standard errors.

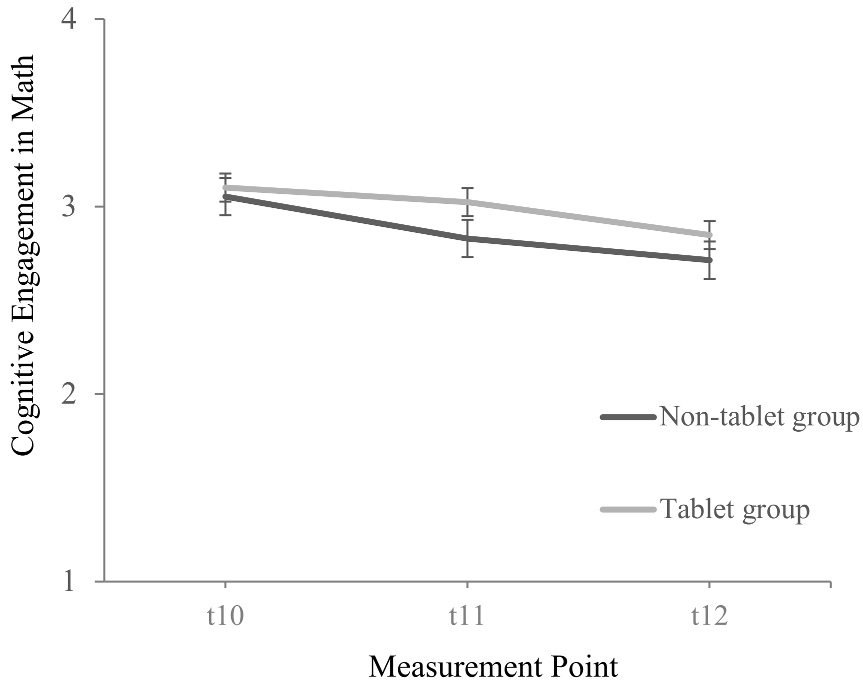
The next step was to test whether the latent changes (i.e., short-term = $Diff_{t0t1}$; long-term = $Diff_{t0t2}$) in students' situational interest were significantly different between the two conditions. First of all, when comparing the means of situational interest at t_{10}, we found no significant baseline difference in situational interest in mathematics classes (SIM) between the tablet and non-tablet groups (p = .077). This result indicated that the two groups of students did not differ in situation interest at the beginning of the study. Additionally, the results showed that the short-term changes in SIM between the first (t_{10}) and second (t_{11}) measurement points were significantly different between the two groups, $Diff_{t10\_t11}$ = .17, SE = .08, $p < .05$, d = 0.50. Therefore, the results indicated that in the short-term (across 4 months), the students in the tablet group had a significantly slower decline in their situational interest in mathematics classes, compared to the ones in the non-tablet class. However, when looking at the latent changes between the first (t_{10}) and third (t_{12}) measurement points, the significant between-group difference in the changes was not found ($Diff_{t10\_t12}$ =.10, SE = .14, p = .10). Thus, the use of tablets did not predict a significant difference in changes in situational interest in the long run.

Taking together, after analyzing and comparing the longitudinal changes in the two groups, we knew that the use of tablet computers significantly predicted a short-term change in students' situational interest. Nevertheless, it did not predict a significant long-term change in students' situational interest in mathematics classes. In addition to the significance test, more details about the effect sizes of these between-group mean differences at each measurement point were presented in Appendix C5.

Regarding the second outcome variable, as illustrates in Table 5.1, compared with the students in the non-tablet class condition, the students in the tablet class condition reported higher mean values in cognitive engagement over the three measurement points. When making the longitudinal comparison, Figure 5.4 shows that the students' cognitive engagement declined in the short term (from t_{10} and t_{11}) and in the long term (from t_{10} and t_{12}). This decreasing trend in cognitive engagement was observed in both tablet and non-tablet groups.

Figure 5.4

Changes in Cognitive Engagement Across Three Measurement Points



Note. This graph demonstrates the changes in students' cognitive engagement in mathematics classes across three measurement points. t_{10} = first measurement point (baseline); t_{11} = second measurement point; t_{12} = third measurement point. Error bars represent standard errors.

Furthermore, according to the multiple-group model results, there was no significant baseline difference between the tablet and non-tablet group (p = .310) on cognitive engagement at t_{10}. Therefore, the students from the two groups did not show a significant difference in cognitive engagement before the intervention. Furthermore, when comparing the latent changes in cognitive engagement between the two groups, the results indicated a significantly latent mean difference in the short-term (between t_{10} and t_{11}), $Diff_{t10\_t11}$ =.11, $p < .001$, $d = 0.28$. It means that the decline in the tablet group in cognitive engagement was significantly smaller than the non-tablet group in the short run (across 4 months). However, expanding the examinations between the first and third measurement points (from t_{10} to t_{12}), the results did not identify a significant difference in the latent changes in cognitive engagement between the two groups ($Diff_{t10\_t12}$ =.01, p = .36). Thus, the use of tablet computers in mathematics classes did not significantly predict the long-term change (across 16 months) in students' cognitive engagement.

To sum up, compared with the non-tablet class condition, the students from the tablet class had higher values in situational interest and cognitive engagement at all three measurement points. When comparing the latent changes of tablet and non-tablet classes, the results showed significant differences in the short-term changes in situational interest and cognitive engagement. However, there was none statistically significant between-group difference in the long-term changes relating to the students' situational interest and cognitive engagement. Therefore, it seems that the use of tablet computers did not predict a long-term influence on student involvement but only makes a difference in the short run.

RQ2: Quantity of Integration of Technology

The second research question was posed to examine whether the changes in students' learning responses were associated with the quantity of using tablet computers. The students in tablet class condition rated their average frequency of using tablet computers in mathematics classes was 13.71 times (ranging from 0 to 20 times, *SD* = 5.95) between measurement points t_{10} and t_{11}. Besides, the average using frequency between measurement points t_{11} and t_{12} was 13.51 times (*SD* = 6.40).

Using the baseline latent change model, we examined the effect of tablets using time on student involvement in mathematics learning over time. The results showed that the frequency of using tablet computers significantly predicted the changes in situational interest in mathematics classes for the short term (for four months between t_{10} and t_{11}), $\beta = 0.19$, $SE = 0.07$, $p = .003$. The more often the tablet computers were used, the less students' situational interest declined in the short run. However, when concerning the long-term impact (for the 16 months between t_{10} and t_{12}), the using frequency had no significant influence on the changes in situational interest. Therefore, the quantity of the use of tablet computers positively predicted a slower decline in situational interest only for a short while. In addition, for the baseline LCM with frequency as the predictor, the indices showed a good model fit: $\chi^2 = 245.53$, $p < .001$; RMSEA = .03, 95% CI [.024, .034]; CFI = .99; and SRMR = .04.

Furthermore, regarding the regression of the second dependent variable, the indices showed a good fit of the baseline LCM, which involved frequency as the predictor and the latent change in cognitive engagement as the outcome variable: $\chi^2 = 107.31$, $p < .001$; RMSEA = .04, 95% CI [.03, .05]; CFI = .98; and SRMR = .04. Based on this model, the results indicated that the frequency of the use of tablet computers had a significant influence on the changes in students' cognitive engagement between the first (t_{10}) and second (t_{11}) measurement points, $\beta = 0.25$, $SE = 0.07$, $p = .001$. From this finding, we knew that the using frequency significantly predicted the changes in cognitive engagement in the short-term (4-month). Besides, when extending the examination, the results found that the effect of using frequency was also significant on the changes between the first (t_{10}) and third (t_{12}) measurement point, $\beta = 0.15$, *SE* = 0.05, *p* = .002. Therefore, the more frequent use of tablet computers positively predicted a slower decline in cognitive engagement. These positive influences on changes in cognitive engagement were significant in both the short and long term (16-month period).

Taken together, the findings indicated that a higher frequency of use of tablet computers in mathematics classes predicted a more substantial change in both students' situational interest and cognitive engagement across a short period of time. However, the positive effect of frequency of use had a long-term effect only on cognitive engagement, but not on students' situational interest.

RQ3: Quality of the Integration of Technology

The third research question focused on whether the quality of using tablet computers would influence individual changes in situational interest and cognitive engagement. Quality of integration was indicated by two types of implementation: enhancement and transformation. Table 5.1 shows that for the situations in which tablet computers were used for enhancement (i.e., to make calculations, to draw graphs, and to do homework) tended to increase across two measurement points (t_{11} and t_{12}). However, regarding the use of tablet computers to do transformations (i.e., to work with the learning program, to conduct simulations), the reported numbers decreased over time.

Using the baseline latent change model, we examined the effect of the tablet-related classroom activities on students' situational interest in mathematics learning over time. For the first model, which involved enhancement type of classroom activities as the predictor, the results indicated no statistically significant influence on changes in situational interest between the t_{10} and t_{11} measurement points (4 months), $\beta = .16$, $SE = .09$, $p = .08$. Moreover, when looking at the effect of enhancement between the t_{10} and t_{12} measurement points, the results also did not identify a significant influence on the changes in situational interest ($\beta = .03$, $SE = .11$, $p = .78$). Therefore, integrating tablet computers to enhance teaching and learning did not predict changes in students' situational interest in both the short-term and long run.

For the second model, which involved transformation type of classroom activities as the predictor, the results showed that this type of implementation did not significantly predict changes in students' situational interest in mathematics classes between the first and second measurement points ($\beta = .20$, $SE = .18$, $p = .28$). Also, none statistically significant was found in the changes in situational interest between the first and third measurement points ($\beta = .13$, $SE = .11$, $p = .20$). The above findings concluded that the use of tablets for transformation types of activities did not impact situational interest across a short (4 months) or a long period (16 months).

Next, using the baseline latent change model, we also examined the effect of two types of technology integration on cognitive engagement. The results indicated that the enhancement-related classroom activities did not significantly predict the changes in cognitive engagement between t_{10} and t_{11} measurement points ($\beta = .21$, $SE = .02$, $p = .07$). Furthermore, the results showed no statistically significant prediction of enhancement type of activity between t_{10} and t_{12} ($\beta = .14$, $SE = .08$, $p = .09$). Based on the above findings, we know that when tablet computers were used to enhance cognitive engagement in mathematics classrooms, it did not change the students' cognitive engagement in both short-term (4 months) and long-term (16 months). However, when looking at the transformative use of tablet computers for classroom activities, the results suggested a significant influence on changes in cognitive engagement between t_{10} and t_{11} ($\beta = .09$, $SE = .04$, $p = .025$). Furthermore, a significant influence was found between t_{10} and t_{12} ($\beta = .26$, $SE = .07$, $p < .001$). Therefore, when the tablet computers were used to transform teaching and learning, it predicted a weaker decline in students' cognitive engagement in both the short-term and long-term. In sum, the significant persistent changes in students' cognitive engagement were predicted by using tablets in the transformative type of classroom activities, but not by the enhancement type of use.

5.5 Summary

The purpose of this study was to examine the association between the use of tablet computers and the latent change in student involvement in mathematics learning in a longitudinal sample of students. The results of the current study indicated that in mathematics classes, the students from the non-tablet class showed a declining trend in situational interest across an extended period of time (i.e., 16 months). By contrast, the students in the tablet class exhibited a short-term increase (i.e., 4 months between the first and the second measurement points). Still, in the long run, the students' situational interest declined again (i.e., 16 months between the first and the third measurement points). Additionally, the evidence was fairly clear that the decrease in students' situational interest was statistically significantly different between the tablet and non-tablet classes for the short term. Across four months, the students in tablet class had a significantly slower decline in their situational interest in mathematics instruction. However, this positive effect of using tablets was found only in the short-term (4 months), but not in the long run (16 months). Besides, regarding the persistent changes in cognitive engagement, the students in the non-tablet class also showed a significantly more substantial decrease in their cognitive engagement in the short term (4 months) compared with those in the tablet class. However, there was no significant difference in the changes in the student involvement for either dimension between the two classes in the long run. Overall, the results are in line with the expectations.

The current findings seem to suggest that the use of tablet computers significantly raised students' active involvement in mathematics learning for a short period. Meanwhile, it is vital to notice that the positive consequence in students' situational interest in math may be due to a novelty effect of using tablet computers, but rather, not consist of a longer period of time. The learning process starts with the integration of innovative technology and a lot of excitement but may change students' motivational, cognitive, or behavioral responses. Building on the novelty effects of using tablet computers on student involvement in mathematics learning processes, it is clear that the technology per se does not play the primary role. Instead, how the technology is integrated into the classrooms is what matters.

The present study also examined how the use of technology would influence student involvement over time. To have an in-depth exploration of the mechanism, the investigation focused on the condition in the tablet group and explored the quantity (RQ2) and quality (RQ3) of how the tablet computers were implemented during the mathematics instructions. Regarding the quantity of integration, the empirical evidence showed that the higher frequency of use positively influenced students' situational interest and cognitive engagement, but only for the short term. In addition to the amount of working time, the present study found that the integration of tablet computers in different types of classroom activities impacted students' cognitive engagement over time. Therefore, taking this finding as a reference, it seems that if teachers integrate technology into transformative types of classroom activities would weaken the decline in students' cognitive engagement over time. Moreover, using tablet computers to do less sophisticated activities (e.g., to make calculations, to draw graphs, or to do individual homework) does not activate the potential that technology holds to change students' learning responses. In short, there are no simple answers to the most effective integration of tablet computers in mathematics classrooms (Ainley et al., 2008; Donnelly et al., 2011). The above findings on the quantity and quality of integrating tablet computers provided additional clues for how technology should be integrated into mathematics instruction to reach higher usefulness. More discussion about the limitations, implications of the current study, and suggestions for future research are provided in Chapter 7.

6

Student-Perceived Adaptive Teaching and Student Involvement Instruction

Chapter 6 described *Study 3* and reported the method and results in details. Developing the research questions and preparing the analytic approach were supported by my supervisors. I am grateful for the comments provided by the dissertation committee. Therefore, in the 6.2 Research Question and 6.3 Method, the plural form of the first person "we" was used to address team effort. But the body of the present chapter was written by the sole author.

Chapter 6 Student-Perceived Adaptive Teaching and Student Involvement in ICT-Based Instruction

As described in the previous chapters, *Study 1* found that the integration of tablet computers positively predicted a higher level of students' situational interest and cognitive engagement in mathematics classrooms than the regular classes. Additionally, *Study 2* found that the use of tablet computers significantly enhanced students' interest and slowed the decline in cognitive engagement over a short time. Despite this empirical evidence, the reason for technology's positive influence on student learning processes remains unclear. Therefore, this chapter will explore the processes of how the use of technology influences student involvement in mathematics learning. To investigate the possible factor that impacts the relationship between the use of technology and student learning processes, the role of students' perception of adaptive teaching was examined. As part of the tabletBW research project, the present study (*Study 3*) investigates whether the impact of using tablet computers on student involvement in the mathematics learning is dependent on the potential of technology to facilitate adaptive teaching.

6.1 The Present Study

As previously discussed, individual students differ according to motivational (e.g., academic interest and academic self-concept) and cognitive characteristics (e.g., domain-specific prior knowledge). These differing characteristics shape students' perceptions of class instruction (Seidel, 2006) and interpretation of teaching interventions (Doyle, 1977). In academic settings, students with differing perceptions and learning needs often encounter a "one-size-fits-all" class structure in which a rigid teaching style may fail to support their needs adequately. Several previous studies pointed out that the inappropriate difficulty level of subject matter (i.e., too easy or too hard) caused frustration, disengagement, and a lack of motivation among students (Blayney et al., 2015; Sweller, 1994). Providing appropriate learning opportunities that facilitate all students' learning is a critical issue in education.

Education researchers recommend that teachers vary teaching strategies and customize their instructions to provide students with individualized learning content and activities (Tomlinson, 2000). Conventional teaching processes fail to account for diversity and cannot provide optimal individualized learning opportunities to students. Given these limitations of the traditional approach, educators have emphasized the importance of schools' and teachers' responsiveness to provide equal opportunities for their students. Additionally, education researchers have examined how teaching processes could be tailored to ensure effective learning for each student (Allen et al., 2016; Bimba et al., 2017; Corno & Snow, 1986). According to Corno and Snow (1986), "adaptive teaching" refers to flexible educational approaches and techniques that accommodate individual differences in characteristics and learning needs. Specifically, teaching that is customized (i.e., based on students' individual learning requirements) enhances active learning and stimulates students' learning responses (Moreno & Mayer, 2000).

It is a significant challenge for teachers who often lead classes of students to provide sufficient adaptation to meet each student's unique learning requirements. Though educators have attempted to implement adaptive teaching in the classroom environment, such efforts have been mostly ineffective due to restrictions on time and effort. However, a recent study has found that the use of technology has the potential to adjust the pace and scope of classroom learning to meet the needs of individual students (Scheiter, 2017). Additionally, technology can create opportunities to enhance meaningful learning (Cheung & Slavin, 2013). For example, a recent study found that mobile technology could foster personalized learning by providing unique learning tasks for each student (Song et al., 2012). With the assistance of technology, teachers have higher possibilities to provide diverse content, assessment forms (Gouli et al., 2001), and more individualized feedback (Lefevre, 2013), thus implementing tangible changes in the learning environment (Paramythis & Loidl-Reisinger, 2004). Research on technology-enhanced learning has found that specific technological applications positively affected students' cognitive engagement and interest development (Han & Finkelstein, 2013b; Pellas, 2014). In addition to its contribution to adaptive teaching, ICT-based instruction could expose students to higher-order thinking and enhance active learning (Hopson et al., 2001; Lee & Choi, 2016). Little empirical research has investigated the potential of technology to support adaptive teaching and contribute to student learning processes. No persuasive evidence exists to explain the indirect link between the use of technology and student involvement in learning processes.

Moreover, the concept of adaptive teaching has not been sufficiently defined in previous literature. Some other possible obstacles to researching this topic are the uncertainty of the corresponding activities and assessment of adaptive teaching. In response to this, the current study attempts to gather some clues of students' experiences in adaptive teaching based on their perception. Perception has been defined as the complex sense of people and the environment generated by an individual during interactions with these external factors (Travers, 1982). Although some of the learning experiences that are unobservable directly from students' behaviors, they can be demonstrated by that person's perception. Therefore, students' perceptions of the learning process have received substantial attention in education research (Barbara M Byrne, 1996). Based on this argument, students' perceptions of adaptive teaching reflect their experience activities that accommodate individual characteristics and learning needs. If adaptive teaching is clear and optimal to support student learning in a particular situation, the student will develop a positive perception of that experience and vice versa (Stuve, 2015). A student's experience of adaptive teaching will be reflected in his or her perception of adaptive teaching. Previous researchers have noted that it is difficult to assess and evaluate adaptive teaching in classroom environments (Dumont, 2018); however, it is reasonable to assume that students' perceptions of adaptive teaching can indicate the adaptive teaching process.

The present empirical study aims to examine the interplay of tablets' use, students' perceptions of adaptive teaching, and active learning processes. The study investigates how the use of tablet computers—a popular mobile technology widely available in school settings—can contribute to students' learning responses. Specifically, it explores the role of students' perceptions of adaptive teaching in the relationship between the use of tablets and student learning processes.

6.2 Research Questions

Enhancing student learning is not the only criterion for evaluating the effectiveness of using tablet computers in the classrooms. Supporting teachers to provide high-quality instruction is another potential of technology. As discussed earlier, adaptive teaching is a criterion for high-quality teaching (Wang, 2001). Depending on teaching purposes, the implementation of adaptive teaching can take place in three facets: adaptive content, adaptive assessment, and adaptive feedback. The critical role of adaptive teaching for student learning is widely recognized, and the superiority of being adaptive is widely reported in previous research (Park & Lee, 2004). However, the difficulties of classroom implementation hinder the teachers from addressing all students' learning needs and prerequisites during the instruction. Previous literature has suggested that technology has the potential to support teachers in adjusting their instructions to meet the learning needs of individual students (Anand & Ross, 1987; Brusilovsky & Millán, 2007). Concerning this influence, the use of tablet computers in mathematics classes will be a positive predictor of students' perceptions of adaptive teaching.

To further investigate the students' experiences of adaptive teaching, the first research question aims to identify the impact of the instructional condition (non-tablet class vs. tablet class) on student-perceived adaptive teaching.

RQ1: Do students' perceptions of adaptive teaching associated with the integration of tablet computers in mathematics classrooms?

On the one hand, this study tried to investigate the effect of adaptive teaching on student involvement in mathematics learning processes. Previous literature has suggested that matching teacher instructions to student learning needs can help individual students effectively use educational opportunities (Wang, 2001). In other words, learners who receive appropriate instruction are more likely to engage in learning activities than those who do not. According to the adaptive potential of technology (Scheiter, 2017) to provide personal feedback (Bimba et al., 2017), adaptive assessment (van der Kleij et al., 2012), it is reasonable to expect a contribution to the student learning experience in the classroom. Therefore, it is assumed that students' positive perceptions of adaptive teaching will positively influence students' interest and engagement in the learning processes. Based on these assumptions, students who perceive high levels of adaptive teaching, adaptive assessment, and adaptive feedback are expected to have a higher situational interest and cognitive engagement.

On the other hand, the present study attempts to provide further insight into the process of how the use of tablets could influence student involvement in mathematics learning. The above research question builds on the hypothesized relationship between the use of tablet computers and adaptive teaching (RQ1). It is expected that the use of tablet computers will positively predict adaptive teaching, which will predict higher levels of student situational interest and cognitive engagement. To achieve the above objectives, the second research question was addressed as follows.

RQ2: Do students' perceptions of adaptive teaching mediate the relationship between the use of tablet computers and student involvement in learning processes?

6.3 Method

6.3.1 Sample

For the purpose of this study, student data were drawn from the second measurement point of the tabletBW research project, which involved two cohort panels (t_{11}, t_{21}). The sample consisted of 2,286 seventh graders (51% female) drawn from 28 upper secondary schools across Baden-Württemberg, Germany. The participants were drawn from two panels of the cohort. In Cohort 1, the students ranged in age from 12–18 years (*M* =13.39, *SD* = 0.68), and the students in Cohort 2 ranged in age from 12–19 years (*M* = 13.41, *SD* = 0.68). Participants were assigned to either the non-tablet (*n* = 1,016) or the tablet class condition (*n* = 1,220). The participants in the latter condition had worked with personal tablet computers for four months in their mathematics classes.

6.3.2 Measures

Integration of Technology. The predictor variable of this study was the use of tablet computers in mathematics classrooms. The predictor was indicated by a dichotomous variable coded as 0 (no use of tablets) and 1 (use of tablets).

Perceived Adaptive Teaching. For this study, we analyzed the seventh-grade students perceived adaptive teaching in mathematics classes. According to the theories, the phenomenon of adaptive teaching can be distinguished into three facets: adaptive content, adaptive assessment, and adaptive feedback. In order to assess the students' perception of all three facets, three scales were administered. The scales were adapted from published instruments designed to assess students' perceptions of and experiences with adaptation in the classroom (Bürgermeister et al., 2011). A slight modification was made to the instrument items to distinguish between tablet and non-tablet class conditions. The wording was strictly parallel on the three scales, except for the distinction between the non-tablet class and tablet class conditions. Questionnaire items were generated to reflect the extent of adaptive teaching based on respondents' learning experience in a specific situation. Students rated their opinions based on a four-point Likert scale that ranged from 1 (*does not apply at all*) to 4 (*totally applies*). Cronbach's alpha was used to estimate the reliability of the selected scales. Additional description of the sample items of all subscales is available in the supplemental materials (see Appendix A2).

Adaptive Content, as the first facet of the student perceived adaptive teaching, refers to teaching content and materials that are modified by teachers to account for individual learning needs. The first subscale was designed to assess students' perceptions of the extent to which their teacher accommodated the class content based on students' understanding and learning needs (Bürgermeister et al., 2011). The scale was comprised of five items. The statement was explicitly constructed in the context of mathematics (e.g., "In a mathematics class, our teacher is concerned about how well I understand the subject matter"). The internal consistency

(Cronbach's alpha) of this scale was high (α = .94). During the study, students were asked to recall their classroom experiences, which indicate a certain level of adaptation.

Adaptive Assessment, the second facets of the student's perceived adaptive teaching, refers to the procedures by which teachers assess students' level of understanding and monitor learning progress. Students' perceptions of adaptive formative assessment were measured using four items that were customized for this study. Participants indicated their level of agreement regarding the mathematics teachers' identification of students' needs in providing interactive assessments (e.g., "In the mathematics classes, as soon as our teacher recognizes the problem and weakness of each student, he/she will offer help"; Bürgermeister et al., 2011). This scale showed high internal consistency among items (α = .92).

Adaptive Feedback, as the third facet of the student perceived adaptive teaching, refers to the information and comments that are tailored by teachers based on students' responses and learning performance. Five items were used to assess students' perceptions of adaptive feedback in mathematics classes (e.g., "In the mathematics classes, I have experienced how I can improve my weaknesses in learning," Bürgermeister et al., 2011). Participants were asked to recall relevant experiences in the mathematics classes throughout the academic semester. This scale had adequate internal consistency (α = .94).

Student Involvement in Learning. The outcome variable for this study was student involvement during learning processes. Two constructs were used to indicate individual students' involvement in mathematics classrooms: (1) situational interest and (2) cognitive engagement. Students were asked to respond to the statements in the questionnaire based on their experiences in the past four months in mathematics classes. Using self-reports, the student respondents rated their perceptions on a Likert-type scale that ranged from 1 (*does not apply at all*) to 4 (*totally applies*). More supplementary information regarding the questionnaire items is available (see Appendix A3).

Situational interest in mathematics assesses the extent to which a situation attracts a student's interest. It was measured using five items that were successfully applied in prior studies to evaluate students' motivational responses to learning tasks (Knogler et al., 2015). Students in tablet class condition were asked to recall experiences in which they worked with (i.e., tablet group). In contrast, the statements for the non-tablet group were described under the condition of not work with tablet computers. For each specific situation, the students recalled their learning experience in the mathematics classes and rated their agreement with the given statement (e.g., "In the mathematics class, the teaching has captured my attention"). The selected items of the situational interest scale had a high internal consistency (α = .97).

Cognitive engagement in mathematics assesses students' internal behaviors, such as investment of mental effort to learn and quality of understanding, related to their experience in mathematics classes. This outcome was assessed by four items. Specifically, students in the tablet group were asked to consider the given statement only for the mathematics classes in which they have worked with tablet computers. In contrast, the students in the non-tablet group recalled their learning experience in the regular mathematics class without working with tablet computers. Based on the particular condition, they rate their perceptions regarding the devoted mental effort (e.g., "In the mathematics classes, I have worked as hard as I can"; (Rimm-Kaufman et al., 2015). The cognitive engagement scale had high reliability ($\alpha = .93$).

6.3.3 Statistical Analyses

Confirmatory Factor Analyses. In the present study, the construct of adaptive teaching could not be directly observed. Three Likert-based scales were used to assess the three facets of adaptive teaching. Each dimension was addressed using four or five questionnaire items. Prior to evaluating the hypothesized model of adaptive teaching, it was necessary to validate the scales and constructs. Confirmatory factor analyses (CFA) were conducted to test whether the multiple manifest items adequately measured each facet of adaptive teaching. The purpose of this process was to determine whether to eliminate any redundant or unnecessary items from the original scale. Next, each facet of adaptive teaching (i.e., adaptive content, adaptive assessment, and adaptive feedback) was explicitly specified by conducting a three-factor CFA model. Though the three facets are theoretically specific in their focus, it was necessary to determine the number of facets that best represent the construct of adaptive teaching.

To test the hypotheses driven by theory, each manifest item was examined to determine whether it was related to only one facet (factor) of adaptive teaching or multiple factors. In short, the CFA statistical technique enabled analysis of the variance of three facets of adaptive teaching and determined whether each facet was distinguished from the others. Additionally, a chi-square difference test (i.e., the mean-adjusted chi-square) of the one-factor and three-factor models was conducted (Satorra & Bentler, 2001; Satorra & Bentler, 2010) to determine the best-fit model. Specifically, we computed the difference of the chi-square values of the two models as well as the difference of the degrees of freedom, so that to determine which model had a better fit to the data (Werner & Schermelleh-Engel, 2010).

During the CFA process, the model fit was assessed by using a chi-square test, standardized root-mean-square residual (SRMR), comparative fit index (CFI), and root-mean-square error of approximation (RMSEA). The cutoff criteria for the above fit indices were based on the work of Hu and Bentler (1999). A good fit is indicated by CFI indices not smaller than .90 and not larger than .05 for the RMSEA and SRMR. The model fit results supported the assumption that adaptive teaching is a multi-dimensional construct and confirmed that the three-factor model was a good fit (see Appendix D1).

Multiple-Group Models. As noted earlier, the three facets of student-perceived adaptive teaching were the latent variables that indicated by multiple manifest items. To test whether the students' perceived adaptive teaching was different between the tablet and non-tablet class conditions (RQ1), structural equation modeling (SEM) is considered an appropriate approach to evaluate the underlying relationship of multiple observed indicators to the corresponding factor and the relationships between latent variables. Prior to examining the between-group differences in terms of student perceived adaptive teaching, measurement invariance was assessed. In order to obtain the equivalence of the constructs between the two conditions and across time, the strong measurement invariances (i.e., same factor loading and intercepts for each manifest items) for predictor variables and outcome variables were expected to established (Meredith, 1993; Meredith & Teresi, 2006).

The separated multiple-group models (between-design) were applied to examine the differences in three facets of students' perceptions of adaptive teaching (i.e., adaptive content, adaptive assessment, and adaptive feedback) between the tablet and non-tablet classes. Two groups of conditions were recoded into a dichotomous variable that indicated whether participants worked with (= 1) or did not work with (= 0) tablet computers. The latent mean values of the three aspects of adaptive teaching were then calculated for both tablet and non-tablet classes.

The next step was to test whether the differences of latent means for each facet of adaptive teaching (MD_{ac} = the mean difference in adaptive content, MD_{aa} = the mean difference in adaptive assessment, and MD_{af} = the mean difference in adaptive feedback) were significant. Only with the statistical significance of the mean difference was insufficient to understand the magnitude of the difference across two groups. Therefore, the effect sizes of the mean difference were estimated by using Cohen's *d* with pooled standard deviation, as suggested by Sullivan and Feinn (2012).

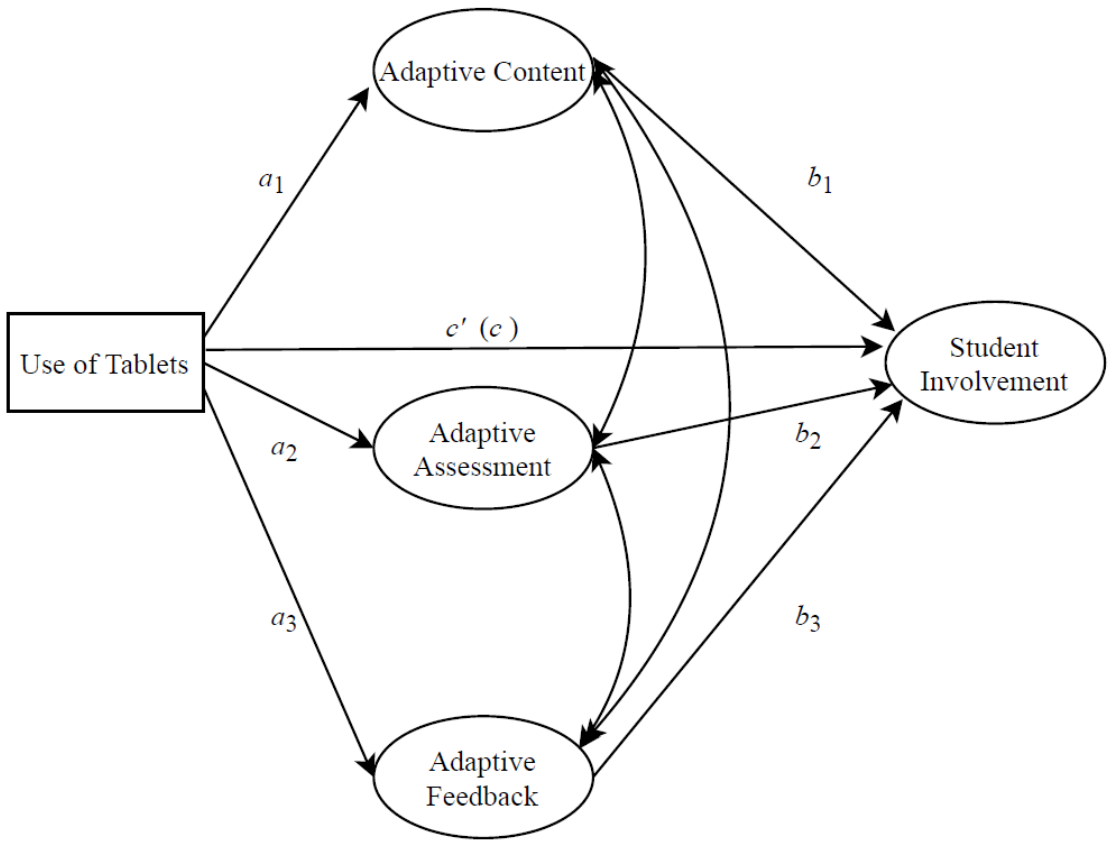
Mediation Analyses with Categorical Variable. Before modeling the mediating effects, correlational analyses were conducted to examine the strength and direction of the relationships among predictor variables, mediators, and outcome variables. To test whether the use of tablet computers influenced student involvement by affecting students' perceptions of adaptive teaching (RQ2), a mediation model was specified (Preacher & Hayes, 2004). Specifically, the purpose of the mediation analyses was to reveal the process by which the initial predictor variable (i.e., use of tablets) influences the outcome variables (i.e., student involvement). Regarding the mediators of the model, they were the three conceptually distinct and not too highly correlated facets of students' perceptions of adaptive teaching. Thus, a linear regression model with multiple mediators was conducted to investigate whether the three facets of students' perceptions had distinct mediation effects between the use of tablets and student involvement.

Followed the suggestion from Hayes and Preacher (2014), the statistical analyses were conducted to specify the mediating mechanisms (see Figure 6.1). Additionally, because the outcome variable —student involvement was captured by two constructs, the mediation effect was tested separately using two models. Taking one of the outcome variables as an example, the first step was to detect a significant total effect (*c*) of the dichotomous predictor variable (tablet versus non-tablet) on the continuous outcome variable (Y: situational interest) in the unmediated model. If the standardized regression coefficient was statistically different from zero, a significant total effect was detected (Hayes & Preacher, 2014). The second step was to test whether X had a significant effect (*a*) on the mediator variable (M). In the current study, there were three parallel mediator variables (i.e., perceived adaptive content, adaptive assessment, and adaptive feedback). As noted previously, the construction of adaptive teaching comprises of three facets. Compared to the single mediator model, the multiple-mediator model was more appropriate to test the perceived adaptive teaching on situational interest (MacKinnon et al., 2000). The third step was to detect a significant effect of the perceived adaptive teaching on situational interest (*b*) when controlling for using tablet computers. In this step, three mediators were all included as the predictors of Y.

Finally, the three mediator variables were included in the regression to examine the effect of using tablet computers on student involvement (*c'*, X|M→Y). Regarding the mediating effect, it was expected that the perceived adaptive teaching would mediate the effect of using tablet computers on student situational interest. Based on the above procedure, the identical statistical analyses were applied to the second mediation model with cognitive engagement as the outcome variable (see Appendix D2 for more detail). Statistical significance tests of the study variables were conducted at the 5% level.

Figure 6.1

Conceptual Diagram of the Mediation Analysis



Note. This is the simplified SEM diagram (see Appendix D2 for the full version). In this hypothesized model, a_i and b_i = indirect effects of the predictor variable (i.e., use of tablet computers) on the outcome variable. c' = direct effects of the predictor on the outcome variable. c = total effect of the predictor on the outcome variable in the non-mediated model.

Cluster Structure and Handling Missing Data. Students in the same class are not entirely independent of one another; therefore, a cluster structure was used to nest the individual student at the class level to avoid underestimation of standard errors (Raudenbush & Bryk, 2002). The individual values of each latent variable were clustered at the class level (*Cluster = Class, type = complex*) in the nested data structure (Geiser, 2013). Besides, during data collection, some students who had initially agreed to participate were absent because of sickness or a change of schedule. There was also some nonresponse in the data, perhaps due to participants' refusing to respond to particular items, participants not knowing the answers, or edit failures. Nonresponses in the survey data were classified as missing random (Little &

Rubin, 2019). Rather than imputing the value of missing data, a full information maximum likelihood (FIML) estimation was used to compensate for random nonresponses (Muthén & Muthén, 2017; Schafer & Graham, 2002). The present study applied the bootstrapping approach with a 95% confidence interval to test an indirect effect in the hypothetical population. The SEM analyses, Goodness-of-fit testing, and FIML estimation were all performed using the Mplus software (Version 8.0; Muthén & Muthén, 1998–2017).

6.4 Results

Evaluation of the Three-Factor Adaptive Teaching Model

The primary goal of the present study was to investigate the student-perceived adaptive teaching from three particular facets and whether these student perceptions mediated the relationship between tablets use and student involvement in mathematics learning. In the present study, it was assumed that adaptive teaching involved three facets: perceived adaptive content, perceived adaptive assessment, and perceived adaptive feedback. A set of confirmatory factor analyses (CFA) was computed using the tablet group sample to test whether the hypothesized three-factor model was tenable. First, a one-factor CFA was conducted, which did not distinguish between the three facets of adaptive teaching. All items jointly load on one factor in this model. Besides, in the three-factor CFA model, each facet of adaptive teaching was represented by a single factor. Furthermore, each latent factor was separately represented by multiple manifest items. The hypothesized three-factor model, illustrated in Table 6.1, indicates a good model fit of the data: $\chi^2 = 425.63$, $df = 74$ ($p < .001$); CFI = .98, RMSEA = .05, with 95% CI [.04, .05], SRMR = .02. In contrast, the one-factor model generated a poor model fit to the student data.

Additionally, we computed a chi-square difference test between the one-factor and three-factor model (see Table 6.1). According to the results, because χ^2_{diff} value was statistically significant, the model with fewer degrees of freedom yielded a better fit than the model with more degrees of freedom ($p < .001$). In other words, the results of the chi-square difference test indicated a rejection of the one-factor model. In the three-factor model, the correlations between every two factors were reasonably high (α between .68 and .83). Also, the factor loadings of each item on its corresponding factor were all significant (see Appendix D2). Taking together, the results supported the theoretical assumption that the three facets of student-perceived adaptive teaching were separated and distinguished from each other.

Table 6.1

Results of Confirmatory Factor Analysis and Model Comparison

Model	χ^2			RMSEA		SRMR	CFI
	Value	*df*	*p*	Value	95% CI		
One-factor model[a]	3170.89	77	< .001	.14	[.12, .14]	.08	.814
Three-factor model[b]	454.84	74	< .001	.05	[.04, .05]	.02	.977

Chi-square difference test	χ^2	Scaling correction factor[c]	*df*	c_d	T_d	*p*
One-factor model[a]	3170.89	1.96	77	5.01	542.04	< .001
Three-factor model[b]	454.84	1.94	74			

Note. Structural equation modeling was used for the analysis. The three-factor model denoted the complete CFA model, which includes three parallel facets of adaptive teaching. *df* = degrees of freedom; RMSEA = root-mean-square error of approximation; CI = confidence interval; SRMR = standardized-root-mean square residual; CFI = comparative fit index; C_d = difference test scaling correlation; T_d = mean-adjusted chi-square difference.

[a] In the one-factor model, all 14 items of student-perceived adaptive content, adaptive assessment, and adaptive feedback were loaded onto one factor. [b] In the three-factor model, 5 items of student-perceived adaptive content were loaded onto one factor; the 4 items of student-perceived adaptive assessment were loaded onto a second factor, and the 5 items of student-perceived adaptive feedback were loaded onto a third factor. [c] The scaling correlation factors are the output for the H_0 model.

Correlation and Descriptive Statistics

Table 6.2 displays the standardized correlations among the study variables. All correlations between the two key variables were positive. The use of tablet computers in mathematics classrooms was significantly and positively correlated with three facets of student perceived adaptive teaching. Besides, the use of tablets also had significant correlations with situational interest and cognitive engagement. Additionally, each of the three facets of perceived adaptive teaching was significantly correlated with students' situational interest (standardized correlations ranged from .63–.68, $p < .01$), and cognitive engagement (standardized correlations ranged from .49–.56, $p < .01$) in mathematics classes.

Table 6.2

Standardized Correlations Between Study Variables

	Variable	1	2	3	4	5	6
1	Use of tablets [a]	—					
	Adaptive teaching						
2	Adaptive content	.18**	—				
3	Adaptive assessment	.19**	.83**	—			
4	Adaptive feedback	.12**	.68**	.76**	—		
	Student involvement						
5	Situational interest	.25**	.67**	.68**	.63**	—	
6	Cognitive engagement	.12**	.49**	.53**	.56**	.61**	—

Note. This table presents the standardized correlations between the study variables. The four-point Likert scale measured variables 2–6. Variables 5 and 6 refer to two aspects of student learning responses in mathematics classes. [a] Did not work with tablet computers = 0, worked with tablet computers = 1.
** $p < .01$, two-tailed.

RQ1: Differences Between Groups in Students' Perceptions of Adaptive Teaching

Table 6.3 presents the descriptive statistics of students' perceptions of the three facets of adaptive teaching among the tablet and non-tablet groups. According to the results, the students in the tablet group had a higher mean of the perceived adaptive content, perceived adaptive assessment, and perceived adaptive feedback than students in the non-tablet group.

Additionally, we compared the mean differences between the two groups. Findings of the multiple-group comparison identified significant mean differences (MD) in student perceived adaptive content (MD_{ac} = 0.32, SE = .08, $p < .001$, Cohen's d = 0.37), perceived adaptive assessment (MD_{aa} = 0.31, SE = .08, $p < .001$; Cohen's d = 0.40), and perceived adaptive feedback (MD_{af} = 0.19, SE = .07, p = .003; Cohen's d = 0.25) between the two groups. The effect sizes for the significant results ranged from small to medium. Consistent with the proposed hypothesis, students who worked with tablet computers in mathematics classes had higher perceptions of adaptive teaching than students in non-tablet class conditions.

Table 6.3

Descriptive Statistics for Study Variables

Variable	Non-tablet class		Tablet class	
	M	*SD*	*M*	*SD*
Perceived adaptive teaching				
Adaptive content	2.60	0.85	2.92	0.88
Adaptive assessment	2.75	0.79	3.06	0.75
Adaptive feedback	2.97	0.80	3.16	0.76
Student Involvement				
Situational interest	2.36	1.00	2.91	0.83
Cognitive engagement	2.90	0.90	3.05	0.87

Note. Sample of non-tablet class condition n = 1,017; Sample of tablet class condition n = 1,089. Study variables were measured using a four-point Likert scale that ranged from 1 (*does not apply at all*) to 4 (*totally applies*).

RQ2: Perceived Adaptive Teaching as Mediator

RQ2 questioned the mechanism of how the use of tablet computers would influence student involvement in mathematics learning. It was expected that students' perceptions of adaptive teaching would mediate the effect of using tablet computers on (1) situational interest and (2) cognitive engagement. In the present study, the mediation models included three mediators: adaptive content, adaptive assessment, and adaptive feedback.

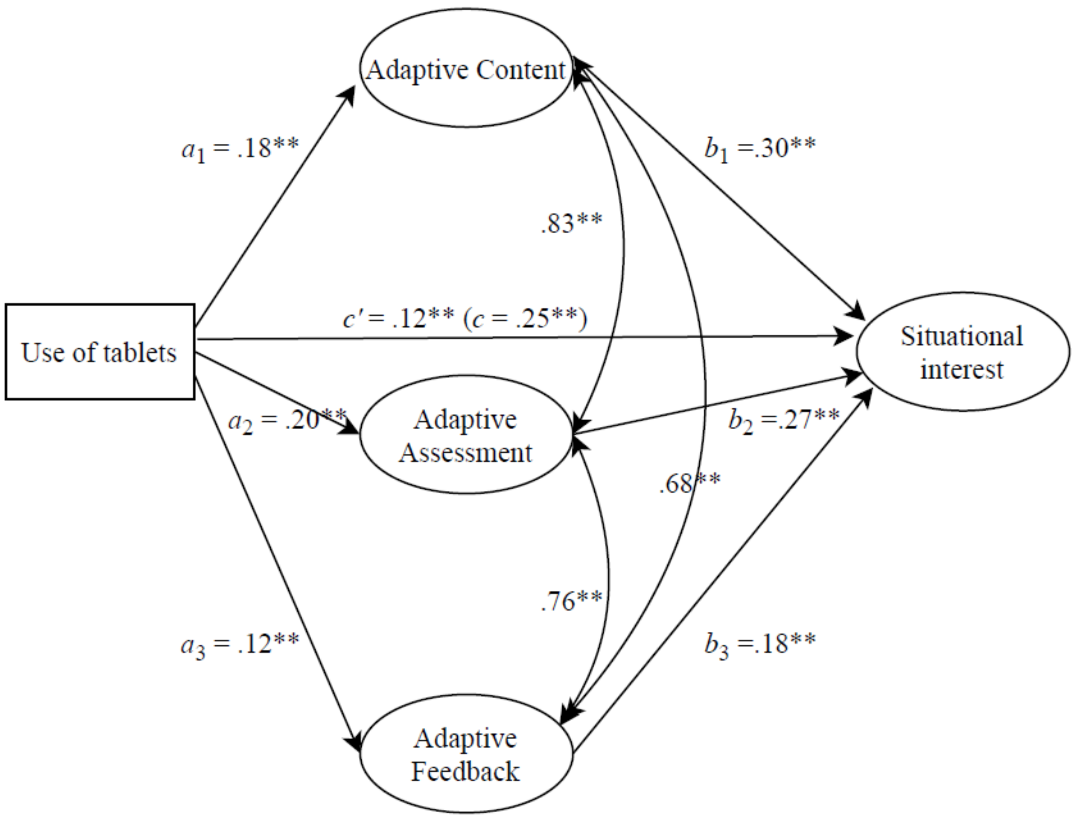
The results of the unmediated model indicated that the total effect of using tablets on student situational interest was positive and statistically different from zero (β_c = .25, *SE* = 0.02, 95% CI [.21, .27], p < .001). Therefore, the use of tablet computers in mathematics classes seems to engender higher situation interest. Moreover, the goodness of fit indices showed that the first mediation model with situational interest as the outcome variable had a good model fit: $\chi 2$ = 1108.59, *df* = 161, p < .001; RMSEA = .05, 95% CI [.05, .06], CFI = .98, SRMR = .02.

As illustrates in Figure 6.2, the results of the first part of the indirect effect (*a*) indicated that the use of tablet computers had a significant influence on the student perceived adaptive content (β_{a1} = .18, *SE* = .02, 95% CI [.14, .22], p < .001), perceived adaptive assessment (β_{a2} = .20, *SE* = .02, 95% CI [.16, .24], p < .001), and perceived adaptive feedback (β_{a3} = .12, *SE* = .02, 95% CI [.08, .17], p < .001). According to the positive standardized regression coefficients, they pointed out that the use of tablet computers in mathematics classes significantly predicted higher student perceptions of the three facets of adaptive teaching.

Figure 6.2 presents the indirect effect (*b*) of the student perceived adaptive teaching on the situational interest. Specifically, the results showed that students' perceptions of adaptive content significantly and positively predicted student situational interest (β_{b1} = .30, *SE* = .04, 95% CI [.23, .36], $p < .001$), as did students' perceptions of adaptive assessment (β_{b2} = .27, *SE* = .04, 95% CI [.19, .35], $p < .001$) and adaptive feedback (β_{b3} = .18, *SE* = .03, 95% CI [.13, .24], $p < .001$). In sum, all three aspects of adaptive teaching positively influenced students' situational interest in mathematics classes.

Figure 6.2

Mediation Model of the Relationship Between the Use of Tablet Computers and Situational Interest



Note. This figure is the simplified version of the SEM mediation model (see Appendix D3 for the full version). In this hypothetical parallel mediator model, all correlation and regression coefficients are standardized. a_i and b_i = indirect effects of the predictor variable (i.e., use of tablet computers) on the outcome variable. c' = direct effect of the predictor variable on the outcome variable. In parentheses, c = the total effect of using tablets on situational interest, controlling for student perceive adaptive teaching.

$^{**}p < .01$, two-tailed.

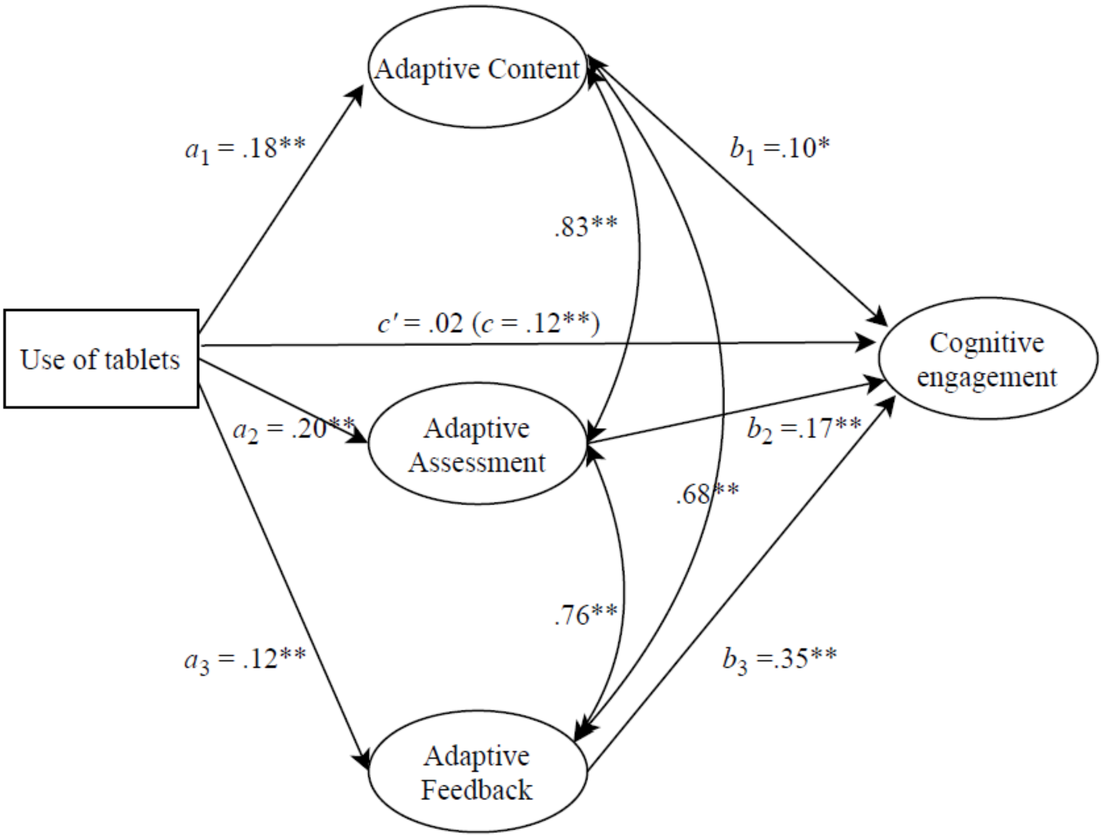
The specific indirect effects (a_n and b_n) of using tablet computers on students' situational interest were all significant. Furthermore, the results also identified a significant total indirect effect of using tablet computer on student situation interest ($\beta_{indirect} = .13$, $SE = .02$, 95% CI [.10, .16], $p < .001$). When the perceived adaptive teaching was controlled, the tablet group still had a higher situational interest. Additionally, in the mediating model, the direct effect of using tablet computers on situational interest (β_c' = .12, $SE = .02$, 95% CI [.09, .15], $p < .001$) was reduced when compared to the unmediated model which did not include students' perceptions of adaptive teaching ($\beta_c = .25$, $SE = .02$, 95% CI [.21, .29], $p < .001$). The standardized regression coefficient of the direct effect remained statistically significant; however, the magnitude of the impact was smaller than the value of the total effect. Therefore, based on this finding, the relationship between the use of tablet computers and situational interest was partially influenced by multiple mediators. In other words, the use of tablets led to an increased situational interest in mathematics in part due to an increase in students' perceptions of adaptive teaching. These findings are consistent with the proposed hypothesis.

Regarding the second outcome variable, the results of the unmediated model indicated that the total effect of using tablets on cognitive engagement was positive and statistically different from zero ($\beta_c = .12$, $SE = .02$, 95% CI [.08, .16], $p < .001$). Therefore, regardless of whether the perceived adaptive teaching was controlled, the use of tablet computers in mathematics classes predicted a higher cognitive engagement. Moreover, the goodness of fit indices showed that the second mediation model with cognitive engagement as the outcome variable had a good model fit: $\chi^2 = 945.94$, $df = 126$, $p < .001$; RMSEA = .06, 95% CI [.05, .06], CFI = .98, SRMR = .02.

Furthermore, the results of the indirect effect (a) indicated that the use of tablets in mathematics classes positively predicted the student perceived adaptive content ($\beta_{a1} = .18$, $SE = .02$, 95% CI [.14, .22], $p < .001$), perceived adaptive assessment ($\beta_{a2} = .20$, $SE = .02$, 95% CI [.16, .24], $p < .001$), as well as adaptive feedback ($\beta_{a3} = .12$, $SE = .02$, 95% CI [.08, .17], $p < .001$). In the current model, these significant results confirm that the use of tablet computers significantly predicted higher student perceptions of adaptive content, adaptive assessment, and adaptive feedback in mathematics classes than those in the non-tablet group (see Figure 6.3).

Figure 6.3

Mediation Model of the Relationship Between the Use of Tablet Computers and Cognitive Engagement



Note. This figure is the simplified version of the SEM mediation model (see Appendix D4 for the full version). In this hypothetical parallel mediator model, all correlation and regression coefficients are standardized. a_i and b_i = indirect effects of the predictor variable (i.e., use of tablet computers) on the outcome variable. c' = direct effect of the predictor variable on the outcome variable. In parentheses, c = the total effect of using tablets on cognitive engagement in mathematics classes, controlling for three aspects of adaptive teaching.
$^{**}p < .01$, two-tailed; $^{*}p < .05$, two-tailed

Moreover, the results of the other part of the specific indirect effect (*b*) indicated that students' cognitive engagement was positively predicted by student perceived adaptive content (β_{b1} = .10, *SE* = .04, 95% CI [.02, .19], *p* = .013), perceived adaptive assessment (β_{b2} = .17, *SE* = .05, 95% CI [.07, .27], *p* = .001), and perceived adaptive feedback (β_{b3} = .35, *SE* = .03, 95% CI [.29, .42], *p* < .001). In other words, higher student perceptions of adaptive teaching predicted higher levels of student cognitive engagement. Furthermore, after taking three mediators into consideration, the results indicated a significant total indirect effect of using tablets on students' cognitive engagement ($\beta_{indirect}$ = .10, *SE* = .01, 95% CI [.07, .12], *p* < .001). Therefore, in the second mediation model, while controlling three parallel mediators, using tablets was found to significantly affect cognitive engagement. Moreover, when reconsidering the direct effect of using tablets, the results of mediation did not find a statistically significant direct effect of using tablet computer on student cognitive engagement (β_c' = .02, *SE* = .02, 95% CI [-.02, .06], $p = .24$). When the perceived adaptive teaching was controlled, the using tablet had no impact on student cognitive engagement.

Finally, as noted previously, results of the unmediated model indicated a significant positive total effect on students' cognitive engagement ($\beta_c = .12$, *SE* = .02, 95% CI [.08, .16], $p < .001$). However, the direct effect of using tablets on student cognitive engagement was no longer significant when multiple mediators were included in the regression model. Taking together, students' perceptions of adaptive teaching fully mediated the relationship between the use of tablet computers and students' cognitive engagement in mathematics classes.

6.5 Summary

The purpose of this study was to investigate the process of how the use of tablet computers influenced student involvement in mathematics learning processes, and whether the student-perceived adaptive teaching mediated this relationship. According to the results of the model comparison, confirmatory factor analysis confirmed that the concept of perceived adaptive teaching could be specified in three facets: adaptive content, adaptive assessment, and adaptive feedback. Additionally, the previous chapter suggested that the use of tablet computers significantly predicted higher situational interest and cognitive engagement in mathematics classes. Building on these former findings, the present study examined the processes of how the use of tablet computers influenced student involvement in mathematics classrooms. This study categorized and assessed the concept of adaptive teaching from three facets: adaptive content, adaptive assessment, and adaptive feedback. This examination added valuable insight into the components of adaptive teaching. Based on the refined constructs of adaptive teaching, this study compared the student perceptions on different facets of adaptive teaching between the control and table classes. The results found that the students in the tablet class perceived a higher level of adaptive teaching, and these perceptions were significantly different from the students in the non-tablet class. The findings support the theory that digital media has the potential to tailor subject content to individual students (Mampadi et al., 2011).

Additionally, the results indicated that students' perceptions of adaptive instruction, adaptive assessment, and adaptive feedback positively predicted situational interest and cognitive engagement in mathematics classes. These findings support prior research findings that teaching characteristics strongly influence student learning (Helmke, 2001). The results also confirmed that the effect of using tablet computers on student cognitive engagement was mediated by adaptive teaching. The findings supported the crucial role of student perceived adaptive teaching in the relationship between the use of technology and student involvement. This insight provides a concrete and comprehensive understanding of the adaptive phenomenon in technology-based instruction. Finally, it is crucial to consider that a strictly planned intervention is necessary to further examine other factors that may contribute to the sustainable and effective use of ICT for learning. Researchers should ensure control in tools and applications before applying them in classroom activities in the future study. Additional discussion about the limitations and implications of the present study can be found in the next chapter.

7

General Discussion

Chapter 7 General Discussion

This dissertation concerns how to provide appropriate learning opportunities and enhance student learning in ICT-based instruction. It focuses on the interplay of individual learning prerequisites, the use of technology, and student involvement in learning processes. The researcher aimed to develop a deeper understanding of the link between learning theories and educational technology by situating existing theoretical models in ICT-based instruction and examining the relationships between class and student factors and technology use. The empirical section of this dissertation comprised three studies that examined the use of tablet computers in secondary school mathematics classrooms. This chapter will summarize and interpret the major findings of the empirical studies and compare them with those of previous studies (7.1). A discussion of the strengths and limitations of the present dissertation (7.2) will follow, including the sample and methodological approach. The next section will use the reviewed learning theories and empirical evidence to provide insight into potential implications for prospective research and classroom practice. Finally, this chapter will conclude with a summary of the most important findings of the dissertation.

7.1 Interpretation of Main Findings

The empirical studies included in this dissertation aimed to explore the interaction of use of tablet computers and student characteristics, to investigate the persistent effect of these interactions on students' learning processes, and to explore the potential of ICT-based instruction to support adaptive teaching (see Table 7.1). Each study begins with a focus on individual learners and ends with a deeper understanding of how to effectively integrate technology into learning. This section will summarize the main findings of the empirical studies and provide an additional interpretation of the results.

7.1.1 Study 1

The purpose of this study was to investigate the relationship between student learning prerequisites and student involvement in mathematics learning and questioned whether this relationship would change under the condition of using tablet computers. The results indicated that students' prior knowledge of mathematics, intrinsic motivation, and math self-concept were positive predictors of their situational interest and cognitive engagement in mathematics classes. The argument of constructivists about leaning is an active knowledge acquisition process was applicable in the ICT-based instruction. The findings also aligned with previous research findings that identified prior domain-specific knowledge as a reliable predictor of student learning (Dochy et al., 2002). Moreover, the results strengthen the argument that particular student characteristics play a crucial role in learning processes and learning outcomes such as academic achievement. Therefore, the findings provide empirical evidence for the supply-use model, which argues that student characteristics are essential prerequisites for further learning (Helmke & Schrader, 2013).

This study also examined the in which condition the effect of individual learning prerequisites on student involvement in mathematics learning changed. The study findings indicated that the relationship between individual learning prerequisites and student involvement was impacted by whether a student had worked with tablet computers in mathematics classes or not. In particular, after working with tablet computers for an academic semester, the magnitude of the effect of students' intrinsic motivation on situational interest becomes smaller. Moreover, for those students who had used tablet computers in mathematics classes, the impact of their math self-concept on students' cognitive engagement decreases. These interaction findings were in line with our expectations. This finding provides empirical support for the conjectures of learning opportunities, and it indirectly indicates that student learning is an ongoing and dynamic development full of changes (Skinner & Pitzer, 2012). Although the positive effect of technology integration on student involvement in mathematics learning is detected, the challenge remains for educational researchers in terms of the mechanisms behind the technology use. Building on the current investigation, it is important to notice that the role of educational technology in the learning processes is critical (Lei, 2010). Simultaneously, this study raises additional questions of whether technology consistently impacts teaching and learning processes and how technology is best integrated into the classroom. These issues were addressed in the next empirical study.

7.1.2 Study 2

The purpose of this study was to examine whether the use of tablet computers enhanced student involvement in mathematics learning over time and explored the mechanisms of technology integration. Given the assumption that tablet usage has a prolonged influence on student involvement in learning processes, Study 2 examined the quantity of quality of using technology that contributes to this influence. Results indicated that students in the control group

Table 7.1

Overview of Three Empirical Studies and Corresponding Aims, Research Questions, Samples, and Study Variables

Study	Aim	Research question	Sample and study variable
Study 1	Investigating the relationship between students' learning prerequisites and student involvement, and in what context this relationship will change	1) What is the effect of individual learning prerequisites on student involvement in mathematics learning processes? 2) Does the use of tablet computers moderate the relationship between individual learning prerequisites and student involvement in mathematics learning?	*N* = 2,286 seventh graders from Cohort 1 and Cohort 2 IVs: Individual learning prerequisites Moderator: Use of tablet computers DVs: Situational interest, cognitive engagement
Study 2	Examining the impact of technology on student involvement in learning processes over time, and generating additional insight into the mechanisms that create these changes	1) Is the use of tablet computers in mathematic classes associated with changes in student involvement in mathematics learning over time? 2) Are the changes in student involvement in mathematics learning associated with the quantity of using tablet computers in mathematics classrooms? 3) Are the changes in student involvement in mathematics learning associated with the quality of using tablet computers in the mathematics classrooms?	*N* = 1,278 seventh graders from Cohort 1 IV: Use of tablets, frequency of use, tablet-related classroom activities DVs: Changes in situational interest/cognitive engagement
Study 3	Identifying how the integration of technology could impact student involvement in learning by exploring the potential of technology to support adaptive teaching	1) Do students' perceptions of adaptive teaching associate with the integration of tablet computers in mathematics classrooms? 2) Do students' perceptions of adaptive teaching mediate the relationship between the use of tablet computers and student involvement in mathematics learning?	*N* = 2,286 seventh graders from Cohort 1 and Cohort 2 IV: Use of tablet computers Mediators: Adaptive content, adaptive assessment, and adaptive feedback DVs: Situational interest, cognitive engagement

experienced a decrease in situational interest in mathematics classes across an extended period of time (16 months). In contrast, students in the tablet group experienced a short-term increase in situational interest in mathematics classes (i.e., over four months from the initial measurement to the second measurement points). Then, even with the working experiences with tablets, a decline in situational interest appears again in the long term (i.e., over 16 months between the second and third measurement point). Therefore, irrespective of whether it has used tablets in mathematics or not, the students' situational interest steadily declined. This decrease phenomenon is consistent with previous literature findings, which pointed out a continuous decrease in mathematics interest during adolescence (Frenzel et al., 2010; Frenzel et al., 2012; Gottfried et al., 2007).

Additionally, in the short term, the difference between the tablet and non-tablet groups regarding changes in students' situational interest was statistically significant, suggesting that the use of tablet computers significantly enhanced students' situational interest in mathematics. However, this enhancement did not continue over a long period of time, and therefore it may, in fact, be due to the novelty effect of using tablet computers. Furthermore, the findings identified that students in the non-tablet group showed a significantly more substantial short-term decrease in their cognitive engagement than those in the tablet group. However, there were no significant between-group differences in student involvement in the long term. Thus, findings in current research consistent with the argument of novelty effect, which claimed a student's excitement of innovative technology is the first response rather than the pattern of implementation that adherence along the learning process (Shin et al., 2019).

The findings reported in Study 2 related to the quantity and quality of integration provided additional evidence for technology use in learning environments. High frequency of technology usage positively influenced students' situational interest and cognitive engagement, though only in the short term. Based on these findings, teachers who wish to see long-term changes in students' cognitive engagement should integrate technology into transformative classroom activities such as working with learning programs and conducting simulations. The use of tablet computers to do less sophisticated activities (e.g., to make calculations, draw graphs, or complete individual homework assignments) does not activate the potential of technology to influence students' learning responses. Study 2 provides useful information on how to achieve a sustained impact on student learning through the integration of technology. Thus, the overall findings provide an insight into the effective integration of technology in mathematics learning and underline the importance of the quality of integration. These results indicate that despite the novelty effect of using tablet computers at an early stage, the technology in itself does not facilitate students' situational interest and promote their cognitive engagement in learning processes. Rather than simply increasing the amount of using time, embedding technology in high-quality classroom activities is the key to effective integration that, in turn, support student involvement in learning.

7.1.3 Study 3

Study 3 aimed to examine the process of how tablet computers influence student involvement in mathematics classes. It hypothesized that students' perceptions of adaptive teaching mediated the relationship between technology integration and student learning processes. According to the results of the model comparison, confirmatory factor analysis confirmed that the concept of perceived adaptive teaching could be specified in three facets: adaptive content, adaptive assessment, and adaptive feedback. Additionally, the study results of the multi-group model indicated that students who worked with tablets for mathematics instruction perceived higher adaptive teaching than those who did not. This finding held for all three facets of student perceived adaptive teaching (i.e., adaptive content, adaptive assessment, and adaptive feedback).

Educational researchers regard adaptive teaching as a critical criterion for effective teaching. During instruction, a teacher gains awareness of individual differences in student learning (e.g., students' motivation or the mental effort they invest in learning activities). The teacher recognizes students' individual learning needs and implements different strategies and content to address those needs and involve students in learning. For example, the teacher may adjust task difficulties according to students' needs. In addition to tailored content and learning activities, teachers provide evaluations and personal feedback in real-time, based on students' responses and performance.

Student diversity growth calls for appropriate teaching methods to accommodate students' strengths and limitations (Suprayogi et al., 2017). On the one hand, teachers have long been expected to accommodate students' learning prerequisites by using diverse teaching methods and technologies. On the other hand, it is enduring attention for researchers in the gap between the ideal classroom situation and reality. The adaptive potential of technology is particularly essential for education in today's world because students have a wider range of individual differences in their motivational and cognitive characteristics. However, the adaptive potential of technology has rarely been examined empirically. The findings of Study 3 indicate that tablet computers do have the potential to support adaptive teaching when integrated appropriately. The empirical findings confirm technology's adaptability potential based on differing student perceptions of adaptive teaching in tablet classes and non-tablet classes. Working with tablet computers can support students in accessing learning opportunities that are suitable for them. Tablets, digital tools, and software offer additional learning alternatives and enable students to study at their own pace.

7.2 Strengths and Limitations

7.2.1 Sample

The sample size is a critical issue that can influence the detection of hypothesized relationships and the statistical power of findings (Peers, 2006). The empirical section of the present dissertation comprised three quantitative studies with different sample sizes. In Studies 1 and 3, the samples of participants were drawn from the second measurement wave of the tabletBW research project (hereafter referred to as the research project), comprised of 2,286 seventh graders. Longitudinal Study 2 involved only Cohort 1 of the research project, comprised of 1,278 students across time measurement points. In quantitative research, sample size adequacy is based on various factors, including pre-statistical analyses (Tanaka, 1987). Despite a general preference for larger sample sizes, education researchers have not reached a consensus that "larger is better" (Borg & Gall, 1989; Slekar, 2005). In other words, the argument regarding the ideal sample size cannot be isolated from the purpose of the study, the predetermined effect size, and the expected power level. Compared to cross-cultural quantitative studies, the number of subjects in the study samples presented in the present dissertation is not substantial. However, the sample size of this project is appropriate, given the difficulties of conducting a field study in a real classroom environment. Importantly, the sample sizes of the research studies included here are large enough to support the statistical analyses.

Generalization is acknowledged as a quality criterion in empirical research, and an appropriate sample draws from a representative population (Polit & Beck, 2010). The participants of these three studies were students in upper secondary school, which is the most demanding school track in the German education system. Variation in the German public-school system ensures that students at the same type of school tend to be at a similar educational level. However, the differences between two school types (e.g., vocation-oriented secondary schools, community schools, and secondary schools) are relatively large. For example, the students in upper secondary schools generally perform better on academic tests than students from other school types, and they are also expected to achieve a higher education level than their peers. The present dissertation focused on individual learning prerequisites (e.g., prior knowledge, intrinsic motivation, and academic self-concept) and active involvement during learning (e.g., situational interest and cognitive engagement), all of which were assessed based on students' self-perceptions. In the literature, these key variables are closely associated with peers (Nagengast & Marsh, 2012) and the learning environment (Lee et al., 2009; Wu, 2003). Therefore, the findings generated from the study samples may not be generalizable to learners from other types of school. It is recommended that future studies obtain a representative sample of the German student population that includes a broad range of students from all types of secondary schools.

7.2.2 Methodological Approach

Study Design. The empirical section of the present dissertation was embedded in the research project, and the methodological approach of the research project and associated studies has several strengths. First, the empirical investigation was conducted as field research in a real classroom environment. Therefore, it provides a platform for education researchers to gain insight into technology-based learning in a classroom setting. Rather than participating in laboratory research conducted in an artificial setting, the participants in these studies attended classes and used tablets in a familiar environment and were therefore likely to behave and report genuinely. Thus, this design significantly contributes to the theories of ecological validity (Cole et al., 1997) and mundane realism (Berkowitz & Donnerstein, 1982). A second strength of the research project is the comparison of the non-tablet group and tablet group. Half of the participants were assigned to the non-tablet class condition, and the second half were assigned to the tablet class condition. Those in the tablet class condition were equipped with tablet computers. The third strength is the longitudinal study design of this study. The studies included in this dissertation were based on large-scale databases, employed a considerable sample size, and increased understanding of student learning. However, there are also shortcomings in the study design.

First, as previously noted, random sampling was manipulated at the school level but not at the class or individual levels. Schools made internal decisions about which students would participate in the study, and therefore not every student in the school had an equal chance to participate. (Savović et al., 2012). The absence of a strict randomized control trial (RCT) at the student level makes it difficult to evaluate the intervention effect and further influence the findings (Oakley et al., 2006). An ideal implementation of this research project would: a) randomly select individual participants, and b) randomly assign participants to control or tablet class conditions. A higher level of randomized intervention is recommended for future studies (see Section 7.4).

Second, the nature of a field study includes a lack of strict control of the external environment, and researchers are unable to eliminate confounding variables in these circumstances completely (Cook, 2002). In particular, the characteristics of the classroom environment in a school setting present certain limitations. For example, Doyle (1986) has noted the difficulty of precisely foresee how a learning activity will take place in the classroom environment. Additionally, the process of student learning in the classroom involves many interpersonal events that occur simultaneously. Distracting factors from the external environment make it difficult for researchers to differentiate the effect of the planned variable (e.g. how the tablet computers are used while learning) from other uncontrolled factors (Berliner, 2002). Therefore, the unpredictability and complexity of the learning environment are potential obstacles to controlling extraneous variables in the classroom setting. Considering these restrictions and requirements, this obvious limitation of the field study is possible to improve by alternative research approaches such as using video recording in classrooms, which would be briefly described later in the recommendation for future studies.

As previously noted, field research is necessarily less controlled than an experimental study in a laboratory setting (Cobb et al., 2003). Hence, the third limitation of the present study design is that the researcher had little control over how tablet computers were used during mathematics instruction. Without the ability to manipulate how often, how long, and in what ways teachers and students use tablets within a predetermined period, it is impossible to draw a causal hypothesis regarding tablet computers and active learning processes. Some education researchers have claimed that the nature of teaching involves intervention in the student learning process (Shuell, 1996). The lack of strict intervention is a significant issue of internal validity (Winter, 2000). The implementation of tablets in class was only subject to limited restrictions due to two practical concerns. The first concern is related to the properties of classroom settings, and the second is related to teacher autonomy during the instructional process. German school teachers are free to make their lesson plans, decide how to navigate student learning, and choose techniques to achieve their teaching goals (MKJS, 2016, 2019). Considering this limitation, some supporting information was gathered from mathematics teachers and students who used tablet computers for various activities outside their classrooms (e.g., to do homework). The supplementary overview table provides information regarding the teachers' reports of tablet-related software and is included in the Appendix (see Appendix 7A).

Besides, to generate a better idea of how the devices were utilized during instruction, we gathered information from teachers' self-report questionnaires. Appendix 7B summarizes the software and tablet applications that teachers selected and used in their mathematics classes.

The fourth limitation of the study design stems from inadequate control for the teacher effect (Randler & Bogner, 2008). In the research project, students in the tablet and non-tablet classes were taught by different teachers instead of having the same teacher. Student learning is a consequence of the interactions of teachers, students, and the external environment; thus, researchers have suggested that different teachers could account for differences in student learning (Cohen & Ball, 2001). Due to practical considerations in this field study, it was unrealistic for the participants in the tablet and non-tablet class conditions to be taught by the same teacher. However, adequate control of interventions (e.g., treatment-control design) is desirable and critical for identifying the intervention effects. It is clear that the study design of this intervention has flaws and fails to provide a clear picture of ICT-based instruction. Study design improvements are recommended for future inquiry. However, these limitations can also provide new directions for future research. There is no compelling reason to conduct a perfect intervention in a school setting; however, future researchers should aim for optimal control of tablet computer implementation for teaching and learning purposes. In experimental studies conducted in a laboratory environment, education researchers can manipulate the same settings between tablet and non-tablet groups, except for the use of tablet computers (independent variable) is different. Future studies can benefit from the shortcomings of the current research project and related studies.

In addition to the strengths and limitations of the research project as a whole, there are also specific strengths and limitations of the empirical studies conducted as part of the present dissertation. The empirical studies focused on the interplay of individual learning prerequisites, the use of technology, and active learning in mathematics classes. They were therefore developed with regard to a particular school subject. These subject-specific studies revealed students' cognitive and motivational characteristics associated with mathematics learning, which is helpful but also raises an issue of generalizability to other school subjects.

Instrument and Measures. The three quantitative studies in the present dissertation rely on self-report questionnaires to collect student data. The use of a self-report assessment to test unobservable constructs such as academic self-concept, intrinsic motivation, and cognitive engagement enables quantifications of these constructs. Students were asked to directly recall their corresponding experiences to answer the questionnaires. The students' retrospective responses are intended to accurately capture the individual's state of mind and evaluate a situation. Education researchers have placed a high value on student evaluations and ratings for their ability to provide insight into teaching and learning processes (Fauth et al., 2014; Seidel & Shavelson, 2007). However, the validity of these ratings depends on students' provision of truthful responses and recall of past learning experiences (Huang et al., 1998), which cannot always imply high validity (Wagner et al., 2013).

Furthermore, the self-assessment format may have the potential risk to produce response bias (Van de Mortel, 2008). For example, socially desirable responding (SDR) is a critical issue in many self-report assessments (Holtgraves, 2004). In the present research studies, SDR is most likely to occur in students' responses to the intrinsic motivation scale or self-concept scale. Participants might have self-reported high levels of interest and competence in mathematics learning if they believed these responses would be perceived favorably. The majority of the items in the self-report assessments were based on a four-point Likert scale, and SDR may therefore have influenced the study outcomes (Paulhus & Reid, 1991).

Study 2 relied on a newly developed scale to assess students' perceptions of adaptive teaching, and the scale demonstrated high reliability (α = .92). Measurements of adaptive teaching have not been clearly defined (Dumont, 2018); however, students' experiences of adaptive teaching content, adaptive assessment, and adaptive feedback can provide useful insight. Based on the useful clues, the assessment tools have to be further developed to fully investigate adaptive teaching experiences in schools. Additional instruments and measuring approaches based on reliable theoretical support and systematic assessment are needed for future research.

Statistical Analyses. The three empirical studies included in the present dissertation rely on latent variable models (i.e., SEM) to analyze hypothesized research questions. This analytical approach has advantages for interdisciplinary research. For example, advances in latent variable modeling have led to a broad application of this methodological approach to examine relationships between unobservable constructs and manifest variables (Matsueda, 2012). In educational psychology, the application of latent variable modeling has enabled researchers to expand the scope of their work to assess unobservable constructs. SEM has become a standard analytical approach in social science fields, and it is used to analyze and describe relationships between unobservable variables (Bollen, 2002). This statistical technique was applied in the present research studies to identify and establish the relationships between technology use and multiple student variables with latent structure. However, latent variable models are often implemented without critical consideration of the research design (Nagengast & Trautwein, 2016). Despite the significant advantages of latent variable models, their application in the present studies may present limitations. For example, Study 1 aimed to investigate the interaction effect of the use of tablet computers on the relationship between students' individual learning prerequisites and active involvement in learning. A linear relationship between the use of technology and student learning processes was expected. However, teaching and learning are complicated processes, and oversimplification of this relationship may mask critical findings.

In the longitudinal study 3, the initial positive effect of the use of tablets on student learning was found to decline after a particular time point. Similarly, the Trends in International Mathematics and Science Study (TIMSS) also reported a positive impact of medium use of technology in mathematics performance (Antonijevic, 2007; Grønmo et al., 2015). Nevertheless, the influence in learning changed to negative when computer technology was extensively used (Antonijevic, 2007). Additionally, Study 3 investigated the mediation effect of students' perceptions of adaptive teaching on the relationship between the use of tablet computers and students' active learning. The mediation effect generally refers to a causal relationship between variables (Hayes, 2018). In this case, the study design was insufficient to identify a causal effect of the mediating variable. Therefore, even with more empirical pieces of evidence that indicate the positive effect of technology use, it may be inappropriate to expect a causal relationship between the use of technology and student learning. To overcome this limitation, a recommendation for future studies is to conduct a well-organized intervention better measure the use of technology to distinguish the effect of using technology from other factors in the classrooms (see 7.3.2).

7.3 Implications and Recommendations

7.3.1 For Learning Theories

Existent learning theories encompass a broad range of topics across the fields of psychology and educational sciences. In these fields, rapidly changing constructs and assumptions in student learning require updated guidance at the theoretical level. These changes have resulted from technological advances and heightened attention to individual learning. Comprehensive learning theories are required to address the challenges of modern education. Chapter 2 addressed the connections between the supply-use model (at the class level and student level) and integrating technology, focusing on changes in student characteristics when using technology (2.6.1). A comparison of the individual learning prerequisites between students participating in conventional instruction and those participating in ICT-based instruction clarifies the nature of the learner. In other words, the impact of using technology on student characteristics highlights the necessity of integrating ICT-based instruction into the general theoretical framework of learning. The present dissertation bridges the gap between adaptive teaching theory and technology-based learning by discussing the adaptive potential of technology (2.6.2). Adaptive teaching is widely accepted as a vital criterion for enhancing teaching effectiveness; however, there is no clear definition of adaptive teaching and no concrete guidance on how to implement it. The theoretical section of this dissertation introduced the theory of instruction and situated the essential instructional compositions (e.g., teaching content, assessment, and feedback) within the construct of adaptability. This discussion supports the theory that adaptive teaching can become more than an abstract construct and can be manipulated in particular classroom activities. Connecting the concept of adaptive teaching to classroom activities remains largely theoretical. The adaptive potential of technology plays a critical role in making adaptive teaching applicable to actual teaching practices. Elaboration of the possibilities of using technology to support adaptive teaching narrows the gap between learning theories and classroom processes. Additional discussion about the implication of technology-based adaptive teaching for classroom practices is provided later in this chapter (7.3.3).

In the empirical section of this dissertation, the findings of Study 1 indicate a new relationship between individual learning prerequisites and the student learning process under the condition of using tablet computers. Certain student characteristics are considered preconditions for effective learning and successful academic performance in the original associations addressed in the supply-use model. However, the empirical evidence of the present studies provides new insight into the magnitude of this influence. Individual motivational and cognitive characteristics—such as prior knowledge, intrinsic motivation, and academic self-concept—play a critical role in predicting learning behaviors and learning activities. However, the strength and direction of these predictions can be manipulated. In sum, changes in learning and assumptions of learner characteristics necessitate an update of learning theories.

The present dissertation addresses a small number of factors in the supply-use model. The model is a comprehensive theoretical framework that includes many variables that can influence teaching and learning processes at different levels. Future research could examine the interactions between ICT-based instruction and other variables. For example, the research could address whether parents' attitudes, perceptions, and technology literacy may be influential factors in the effective use of new media in the home environment (e.g., using digital devices after school). Future researchers should continue to explore the relationships between the use of technology and affective, cognitive, and behavioral characteristics of teachers and students to enrich learning theories. According to the theoretical framework of the supply-use model, a range of old and new constructs have reciprocal relationships. Situating the integration of technology in these complex interactions warrants in-depth and continued research investigation. Teacher-student interactions and person-situation interactions remain unclear in the context of ICT-based instruction, leaving space for future researchers to conduct an additional analytical inquiry.

7.3.2 For Future Research

The present dissertation provides an initial investigation of the integration of technology in classrooms and whether and how it influences student learning processes. However, many issues and questions remain unanswered. The phenomena and contexts where technology-related teaching and learning occur should be further investigated and explained in future studies.

The first recommendation of this dissertation is inspired by the limitations of the study design of education research discussed earlier in this chapter. Teaching and learning are complex interactive processes by nature, and much of the education research on this topic, therefore, uses the qualitative method. Certain classroom characteristics (e.g., unpredictability and multidimensionality) obstruct the implementation of strict control (Doyle, 1986; Shuell, 1996). However, future research to explore the effect of using technology on student learning will require well-organized interventions. Specifically, it is recommended that future researchers use a random allocation of individual students to the control and treatment groups (Torgerson & Torgerson, 2001) and attempt to construct an identical setting for all participants.

Additionally, emerging with educational technology, the debate of the relationship between educational technology and teachers has started (Fried & Goldberg, 1978). However, little knowledge and limited empirical evidence on this topic hinder the comprehensive understanding of the interaction between teachers and technology. The discussion of whether the implementation of technology can or will replace teachers in modern education could be explored in future studies. The educational technology should be used as a digital tool that aids teaching and instruction to reach higher effectiveness. Therefore, this is the second recommendation for future research to investigate teachers' roles and their relationship with new technology in future classrooms.

Continuing to discuss the relationship between teaching and the use of technology, the third recommendation concerns the relationship between technology-related research and the development of technology (i.e., tool-centered versus purpose-centered). Based on what is currently known about technology use in education, existing digital devices and programs have long limited technology-based teaching and related research (Kent & McNergney, 1999). Investigations of technology-related teaching and learning have depended on the technology and software programs that have been made available for educational purposes. Therefore, the research goals and study design are not achievable unless specific tools and software can be accessed in classroom settings. However, according to the values provided by the instructional theory, teaching methods should base on the goals of teaching and learning, rather than the digital tools (Schwartz et al., 1999). Following this argument, educational research should not be unidirectional and only reliant on preexisting tools or programs. An alternative suggestion is to strengthen collaborations between program developers and schools.

Ideally, technology can provide optimal support for teaching and learning if it is developed based on the requirements of classroom practices and scientific research, and researchers should therefore take an active role in selecting a learning program that matches study purposes. Study 2 indicated that the quality of technology integration is key for a long-term positive influence on students' active involvement in learning. However, the estimations of the quality of technology integration were limited to the existing software and programs available for mathematics learning (e.g., conducting simulation, calculating, drawing graphs). Consequently, most technology integration in education remains at the enhancement level and has limited application for transformative purposes (Hamilton et al., 2016). Effective learning is dependent on the ways in which people use tools and software. A focus on the quality of integration must not isolate technology as a vehicle from teaching goals, curriculum plans, and student learning needs (Lei, 2010). Rather, these factors should be appropriately observed and manipulated to achieve particular research goals. New programs for learning purposes must be developed to examine the use of technology in higher-order learning.

The fourth recommendation for future study is to explore the potential of technology to support student learning in a broad educational context. Student learning and the external environment are closely interrelated in that the processes of learning are influenced by students' interactions with external technologies and people. In the modern learning environment, researchers must reconsider the nature of student learning. For example, technology in higher education is frequently integrated into a large lecture hall to reach large audiences (Haddad & Jurich, 2002). Does technology used in this way produce a similarly positive effect on students' active involvement in learning compared with the integration of technology in a typical secondary school classroom with fewer students? Based on the findings of person-situation research, it could assume a non-linear relationship between class size and the use of technology (e.g., an inverted U-shaped relationship). In addition to the balance of ideal class size, researchers must consider that technology integration may introduce distraction to student learning and negatively impact classroom management. Previous studies have concluded that small classes are ideal for the introduction of technology (Glass & Smith, 1979; Hanushek et al., 1999); however, new classroom settings may lead to a different conclusion regarding the ideal class size (Brühwiler & Blatchford, 2011). When implementing technology in a real class setting, the optimal class size for ICT-based instruction is a critical factor that remains unclear.

The fifth recommendation for future research is to expand the investigation of technology-enhanced learning beyond classrooms. Enhancing student involvement in learning processes does require support from schools and teachers. Simultaneously, parents and family environments can also motivate students' involvement and facilitate their engagement in using technology for learning (Shin et al., 2019; Vaala & Bleakley, 2015). Therefore, technology-enhanced learning should not be limited to school settings but extend to other external environments. Existing research has not explored whether and how parents use technology to support their children's involvement in learning. Researchers interested in the sustainable use of technology for educational purposes would do well to examine how different technologies implemented in the family environment may change student learning. Situating future studies in family environments or otherwise outside the classroom would provide a complete picture of the use of technology to support learning.

As noted earlier in the limitation of study design, the current research project did not organize a randomized control trial at the individual level. The complexity and unpredictability of the classroom environment make the randomization in educational research full of obstacles (Torgerson & Torgerson, 2001; Torgerson et al., 2013). Besides, even the intervention is well-organized, the information on how students learn, and the way of teaching are still missing (Sherin, 2003). Considering the practical restriction in school settings, recent researchers attempt to use video as a digital tool for classroom observation (Borko et al., 2008; Stigler & Hiebert, 1997). Digital technologies provide support for teaching and learning and assist educational research (Mishra et al., 2016b). For instance, video observation is a common approach for collecting information regarding teachers' and students' behaviors that are situated in particular classroom environments (Hiebert & Stigler, 2000). Through conducting video study, it provides chances for researchers to capture the teacher-student interaction while using educational technology in classrooms (Sherin & van Es, 2005). With the aid of technology (e.g., camera, microphones), the complexity of technology-based teaching and learning processes is recorded for later analysis. Since the classroom processes are captured, the gathered information could also aid the longitudinal analyses of the individual learning while using educational technology (Hiebert et al., 2003). Therefore, for the future studies, the limitation of lack of experimental control and little understanding of how the technology is applied can be minimized by the video observation and video data analyses.

In practices, many potentials of the technology and digital tools stay at the theoretical level without properly implemented in classrooms. Understanding the impact of technology-based instruction and how it takes place in classroom practices is a long-term and ongoing process for scientific researchers and educational practitioners. In future decades, educational researchers and psychologists should continue to examine teaching and learning processes and embrace broader integration of technology in education.

7.3.3 For Classroom Practices

It is critical to consider the potential implications of increasing learning opportunities in classroom practice. Previous literature has addressed the use of technology to facilitate student learning in secondary education. However, schools and teachers interested in pursuing effective ways to use technology in subject-specific classrooms have no concrete solution. The mechanisms that drive the integration of technology into learning remain particularly unclear. Teachers who attempt to situate learning activities in the context of technology often struggle to integrate and associate the use of technology with particular learning tasks. The present dissertation has discussed the corresponding learning theories and has provided empirical evidence concerning how to support the use of technology while teaching and learning. By extending existing findings regarding technology-related learning, the present dissertation supports schools and teachers in understanding the role of technology and providing useful recommendations to integrate technology into classroom practices.

The first implication for classroom practices is the indication that the use of technology has a positive influence on student learning processes. Uncertainty regarding whether to implement technology in the classroom stems from the mixed results of previous studies. However, the empirical findings of the present dissertation provide evidence to support the advantages of integrating tablet computers into mathematics classes. After several months using tablet computers, the effect of students' active involvement on individual learning prerequisites significantly decreased. Teachers of students with diverse motivational and cognitive characteristics could use technology to provide students with an alternative to compensate for the heterogeneity within a class and facilitate students' active engagement in learning processes.

Second, the present dissertation provides an improved understanding of the comprehensive categorization of integrating technology into mathematics classes. To enhance teachers' knowledge of the operationalization of technology in classroom activities, it is helpful to introduce frameworks regarding the levels of technology integration, along with numerous examples. The findings of Study 2 provide insight into the mechanisms of using technology in classrooms. According to the empirical evidence, the quantity of integration (i.e., the frequent use of technology) is vital at the beginning of the integration process. In the long term, the quality of implementation will determine the effectiveness of technology integration. Study 2 categorized the level of integration based on the SAMR model (Puentedura, 2003) and found that technology could be used at the primary level as a simple replacement of traditional paper-based textbooks and blackboard or to support the efficiency of calculation for mathematics learning. Additionally, teachers should implement transformational use of technology to facilitate a prolonged positive effect on student learning. For example, simulation tasks can be situated on tablet computers to support advanced learning. At the advanced level of operationalization, learning activities may be included that would not be possible without technology support.

The Replacement, Amplification, and Transformation (RAT; Hughes et al., 2006) model is an alternative similar to the SAMR model. It can be used to advise teachers about how to integrate technology into different learning activities. Increased empirical evidence and scientific support will help decrease uncertainty and reverse otherwise skeptical attitudes toward integrating technology. In other words, teachers who have a better understanding of the purpose of technology integration will be more confident in using technology in their classes. In other words, it becomes easier for teachers to decide on which technology they might use. Previous positive results from scientific research provide an overview of the benefits of technology-based education to schools and teachers. In turn, based on sound evidence, schools may be willing to invest additional resources to support teachers, such as increasing the use of ICT in teacher training or aiding ensure that teachers have access to the most current ICT knowledge. Additional support and concrete guidance may make teachers more willing to embrace new technologies and tools for daily practice. Prospective teachers also require preparation to account for the growing trend of integrating technology into education. For example, Koehler and Mishra (2009) have noted that technology knowledge plays a critical role in effective teaching.

Finally, the present dissertation provides empirical evidence of the unique potential of technology to support adaptive teaching. Teachers address a wide diversity of students and learning characteristics, and their corresponding classroom activities must adapt. However, agreement on the importance of adaptive teaching does not provide solutions in the form of classroom processes. The present dissertation suggests that technology may provide an alternative method to support adaptive teaching. For example, limited teaching time makes it difficult for teachers to provide individual feedback for each student on their learning performance. Technology's potential for adaptability can aid scaffold learning by providing automatic evaluation based on students' responses (Veldkamp et al., 2011). The present dissertation supports the argument that technology is a vehicle that can be used to serve teaching and learning but not the other way around.

7.4 Conclusion

The present dissertation aimed to generate theoretical and empirical insights regarding the integration of technology in learning and how this integration may influence student learning processes. The initial question posed was *whether* the use of ICT impacts student learning processes. The subsequent investigation queried *when* this influence occurs and *how* the integration of technology influences students' active involvement in learning. While exploring the use of tablet computers in secondary classroom environments, some significant findings are recovered from the empirical fields.

As part of the present dissertation, quantitative empirical research was conducted in real school settings to explain how technology-based education can improve learning opportunities and facilitate students' motivational and cognitive development. The integration mechanism was examined, which revealed the importance of integrating technology with transformative learning activities for advanced learning. Additionally, this dissertation explored the adaptive potential of ICT to clarify how technology can influence student learning processes. The use of technology has challenged the preexisting understanding of student learning, and many individuals have expressed skepticism toward technology-enhanced learning. Research-practice collaboration is vital to minimize uncertainty and ultimately contribute to a supportive learning environment.

ICT-based instruction is a relatively new phenomenon in Germany's educational practices and research. Through empirical study, researchers are beginning to understand the potential of educational technology in the school context. However, an additional inquiry is needed to verify its potential for teaching and learning. The present dissertation provides valuable insight into integrating technology in education and makes a theoretical and practical contribution to the topic. It is clear that technology will continue to expand opportunities in education and many other disciplines.

The development of educational technology provides a new dynamic for teaching and learning that involves significant changes at different levels. During a period of transition, it is reasonable to expect new interactions in the classroom context. Traditional learning environments (e.g., "one-size-fits-all") will be gradually replaced by more flexible instruction, along with a wide range of methods designed to fit different student needs.

Educators and researchers are unlikely to find one best way to ensure effective teaching and quality instruction. It is reasonable to expect considerable changes related to the roles of teachers, students, and technology. However, there is no need for competition between conventional and modern education. Despite the uncertainty of the relationship between teaching and the use of new technology, both of these two factors are crucial for future education instead of one replace the other. The focus of teaching should remain on identifying learners' needs and supporting their academic and cognitive achievement. Education researchers continue to work with schools, teachers, students, and families to achieve this primary aim. In the modern world, students’ individual needs are changing. Teaching and instruction for the new generation of "digital natives" should promote technology literacy skills to support students’ appropriate development in the digital age. This dissertation has presented an active learning process that can be achieved through multiple approaches and has gathered evidence to support the benefits of integrating educational technology in classroom environments. Collaboration between research and classroom practices can support a shared goal to enhance individual development.

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Appendices

Appendix A1

Overview of the Example Items, Number of Items, Cronbach's Alpha for the Scales of Individual Learning Prerequisites

Construct	Items	Number of items	Scale	Cronbach's α
Intrinsic motivation	Mathematics is fun for me.	3	1 = does not apply at all	.93
	I like mathematics.		2 = partially not applies	
	I enjoy working on topics in mathematics.		3 = partially applies	
			4 = totally applies	
Math self-concept	Mathematics classes do not fit me very well. (R)	4	1 = does not apply at all	.73
	I am good at learning mathematics.		2 = partially not applies	
	Mathematics is easy for me.		3 = partially applies	
	I always have problems during mathematics classes. (R)		4 = totally applies	

Note. The items in the intrinsic motivation scale and math self-concept scale are identical for the participants in the tablet and non-tablet groups. Reverse-scored items are denoted with (R). The values were coded in the statistical analyses. Adapted from "Assessing task values in five subjects during secondary school: Measurement structure and mean level differences across grade level, gender, and academic subject," by Gaspard, H., Häfner, I., Parrisius, C., Trautwein, U. and Nagengast, B, 2017, *Contemporary Educational Psychology*, 48, p. 67-84.

Appendix A2

Overview of the Example Items, Number of Items, Cronbach's Alpha for the Adaptive Teaching Scales

Construct	Items	Number of items	Scale	Cronbach's α
Adaptive content	In mathematics classes, our teacher… …take a look at my learning problem. … take a look at how well I understand the learning material. …to ensure my understanding of individual tasks in order to adapt further learning tasks … to adapt his/her lesson to what we have already learned. … gives me immediate reactions to what I have learned.	5	1 = does not apply at all 2 = partially not applies 3 = partially applies 4 = totally applies	.94
Adaptive assessment	In mathematics classes, … …our teacher repeats the short phases to review our learning performance …as soon as our teacher recognizes a student's problems and weaknesses, he/she will provide help. … our teacher modifies his/her the difficulty of the test. … if we do not understand something, our teacher will change his/her plan until it is understood.	4	1 = does not apply at all 2 = partially not applies 3 = partially applies 4 = totally applies	.92

Adaptive feedback	In mathematics classes, I am able to know… …my academic performance. …what I have learned. …what I am not good at. …how I can improve my weaknesses. …how to achieve my learning goal.	5	1 = does not apply at all 2 = partially not applies 3 = partially applies 4 = totally applies	.94

Note. The participants in non-tablet class or tablet class conditions were asked to consider the given statements only for the mathematic instruction in which they (1) worked with or (2) did not work with tablet computers. Adapted from "Dokumentation der Befragungsinstrumente des Laborexperimentes im Projekt "Conditions and Consequences of Classroom Assessment" (Co²CA)," by Bürgermeister, A., Kampa, M., Rakoczy, K., Harks, B., Besser, M., Klieme, E., Blum, W., and Leiß, D, 2011, Deutsches Institut für Internationale Pädagogische Forschung (DIPF), p. 1-93.

Appendix A3

Overview of the Example Items, Number of Items, Cronbach's Alpha for the Scales of Student Involvement in Mathematics Learning

Construct	Items	Number of items	Scale	Cronbach's α
Situational interest[a]	In the mathematics classes, …	5	1 = does not apply at all	.97
	…the classes aroused my curiosity.		2 = partially not applies	
	…the classes captured my attention.		3 = partially applies	
	…the classes were fun for me		4 = totally applies	
	…I enjoyed the classes.			
	…the classes were exciting for me.			
Cognitive engagement[b]	In the mathematics classes, …	3	1 = does not apply at all	.93
	…I tried as hard as I could.		2 = partially not applies	
	…it was important for me to understand things very well.		3 = partially applies	
	…I tried to learn as much as I could.		4 = totally applies	

Note. [a] Adapted from "How situational is situational interest? Investigating the longitudinal structure of situational interest," by Knogler, Harackiewicz, Gegenfurtner, and Lewalter, D, 2015, *Contemporary Educational Psychology*, 43, p 39-50.

[b] Adapted from "To what extent do teacher-student interaction quality and student gender contribute to fifth graders' engagement in mathematics learning," by Rimm-Kaufman, S. E., Baroody, A. E., Larsen, R. A., Curby, T. W., and Abry, T, 2015, *Journal of Educational Psychology*, 107(1), p. 170.

Appendix A4

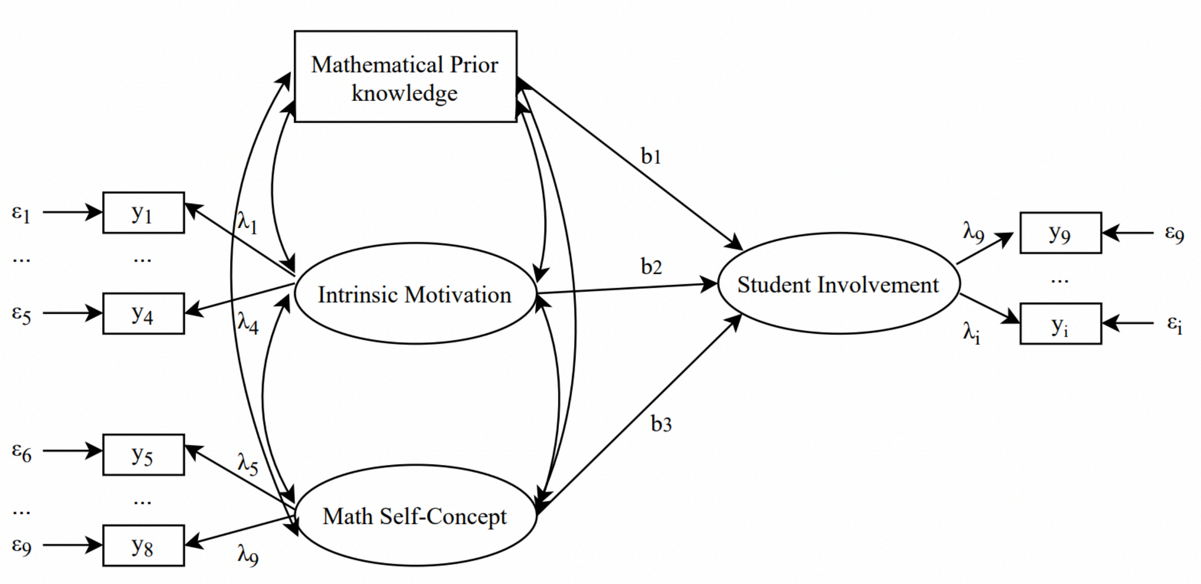
Tablet-Related Classroom Activities in Mathematics Classes

Condition	Items	Number of items	Scale
Non-tablet class (Tablet class)	In mathematics classes, our teacher (use tablet computers) … …to make a PowerPoint presentation. …work with a learning program. …read the text. …write text. …read a digital textbook. …calculate or work with databases. …organize learning materials. …play games. …draw graphs. …browse the Internet. …assess performance. …engage in online communication [a]. …to do programming …conduct simulations. …do individual homework. …do group work. …answer teacher's questions. …provide individual feedback.	18	1 = does not apply at all 2 = partially not applies 3 = partially applies 4 = totally applies

Note. [a] Examples of online communication are chats and forums.

Appendix B1

Hypothesized Structural Equation Model of the Relationship Between Individual Learning Prerequisites and Student Involvement in Mathematics Learning



Note. This is the hypothesized linear regression model of *Study 1* (RQ1).

Appendix B2

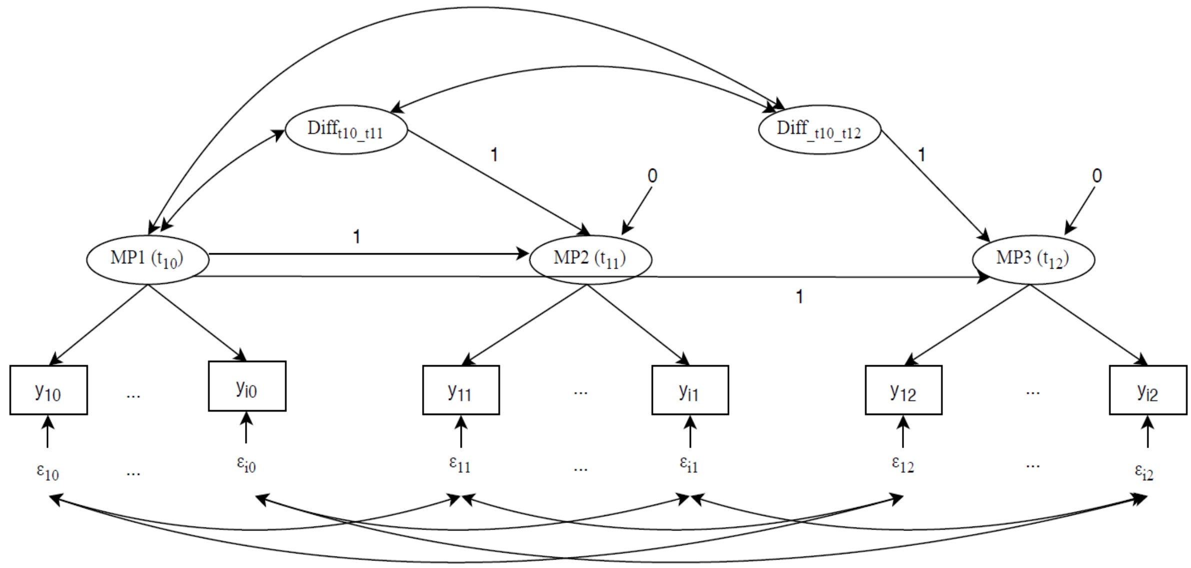
Model Fit Statistics for Linear Regression Models

Outcome variables		χ^2		
		value	*df*	*p*
Situational interest				
RMSEA [95% CI]	.073 [.069, .078]	878.706	60	< .001
CFI	.948			
SRMR	.054			
Cognitive engagement				
RMSEA [95% CI]	.098 [.093, .103]	982.794	39	< .001
CFI	.904			
SRMR	.062			

Note. This table is the model-fit estimation of the regression models in *Study 1* (RQ1). Structural equation modeling was used for the analyses of two outcome variables. CI = confidence interval; *df* = degrees of freedom; SRMR = standardized root-mean-square residual; CFI = comparative fit index; RMSEA = root-mean-square error of approximation.

Appendix C1

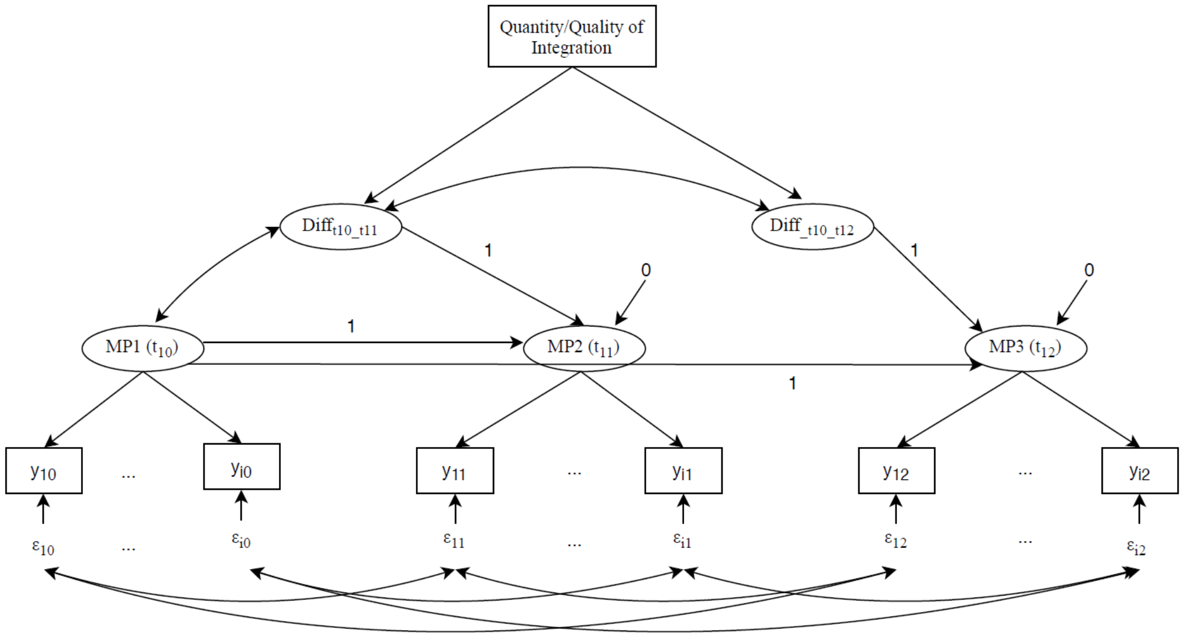
Hypothesized Baseline Latent Change Model



Note. This is the hypothesized baseline latent change model of *Study 2* (RQ1). MP1 = latent variable (i.e., situational interest or cognitive engagement) at the first measurement point. MP2 = latent variable at the second measurement point. MP3 = latent variable at the third measurement point. $Diff_{t10\_t11}$ refers to the change in situational interest between measurement points t_{10} and t_{11}. y_{ij} = the j^{th} item at measurement point *i*. ε = error.

Appendix C2

Hypothesized Baseline Latent Change Model with Mechanism of Integration as Predictor



Note. This is the hypothesized baseline latent change model of *Study 2* (RQ2 and RQ3). MP1 = latent variable (i.e., situational interest or cognitive engagement) at the first measurement point. MP2 = latent variable at the second measurement point. MP3 = latent variable at the third measurement point. Diff$_{t10_t11}$ refers to the change in situational interest between measurement points t_{10} and t_{11}. y_{ij} = the *j*th item at measurement point *i*. ε = error.

Appendix C3

Model Fit Statistics for Baseline Latent Change Models in which the Situational Interest Change Scores were Regressed on the Integration Mechanisms

Model		χ^2 value	χ^2 *df*	χ^2 *p*
Model 1[a]				
RMSEA [95% CI]	.029 [.024, .034]			
CFI	.988	245.529	113	< .001
SRMR	.035			
Model 2[b]				
RMSEA [95% CI]	.026 [.022, .030]			
CFI	.986	345.757	181	< .001
SRMR	.036			
Model 3[c]				
RMSEA [95% CI]	.026 [.022, .030]	277.731	144	< .001
CFI	.988			
SRMR	.043			

Note. This table is the model-fit estimation of the regression models in *Study 2* (RQ2 and RQ3). Structural equation modeling was used for the analyses of two outcome variables. [a] Model 1, the predictor variable was the using frequency of tablet computers between measurement points. [b] Model 2, the predictor variable was the enhancement type of tablet-related classroom activities (i.e., to calculate or work with databases, and to do individual homework). [c] Model 3, the predictor variable was the transformation type of tablet-related classroom activities (i.e., to work with the learning program, to do simulation). CI = confidence interval; *df* = degrees of freedom; SRMR = standardized root-mean-square residual; CFI = comparative fit index; RMSEA = root-mean-square error of approximation.

Appendix C4

Model Fit Statistics for Baseline Latent Change Models in which the Cognitive Engagement Change Scores were Regressed on the Integration Mechanisms

Model		χ^2		
		value	*df*	*p*
Model 1[a]				
RMSEA [95% CI]	.038 [.030, .046]			
CFI	.981	107.312	36	< .001
SRMR	.040			
Model 2[b]				
RMSEA [95% CI]	.031 [.025, .036]			
CFI	.977	182.565	80	< .001
SRMR	.046			
Model 3[c]				
RMSEA [95% CI]	.032 [.026, .039]	134.378	55	< .001
CFI	.981			
SRMR	.046			

Note. This table is the model-fit estimation of the regression models in *Study 2* (RQ2 and RQ3). Structural equation modeling was used for the analyses of two outcome variables. [a] Model 1, the predictor variable was the using frequency of tablet computers between measurement points. [b] Model 2, the predictor variable was the enhancement type of tablet-related classroom activities (i.e., to calculate or work with databases, and to do individual homework). [c] Model 3, the predictor variable was the transformation type of tablet-related classroom activities (i.e., to work with the learning program, to do simulation). CI = confidence interval; *df* = degrees of freedom; SRMR = standardized root-mean-square residual; CFI = comparative fit index; RMSEA = root-mean-square error of approximation.

Appendix C5

Latent Means and Standard Deviations for the Dependent Variables and Between Group Comparisons

Outcome variable	Condition	t_{10}		t_{11}		t_{12}		M_c vs. M_t (t_{10})		M_c vs. M_t (t_{11})		M_c vs. M_t (t_{12})	
		M	*SD*	*M*	*SD*	*M*	*SD*	*d*	*p*	*d*	*p*	*d*	*p*
Situational interest	Non-tablet class	2.46	0.91	2.38	0.98	2.36	0.96	0.268	.08	0.497	< .05	0.295	.10
	Tablet class	2.70	0.88	2.85	0.91	2.64	0.94						
Cognitive engagement	Non-tablet class	3.02	0.69	2.80	0.87	2.70	0.90	0.150	.31	0.284	< .001	0.183	.36
	Tablet class	3.12	0.64	3.04	0.82	2.86	0.85						

Note. The table is the supplementary material for *Study 2* (RQ1). Sample size of non-tablet class condition = 689; sample size of tablet class condition = 674. Situational interest and cognitive engagement were analyzed as two constructs of student involvement in learning processes. Cohen's d refers to the mean difference between the mean in the non-tablet class (M_c) and tablet class (M_t).

Appendix D1

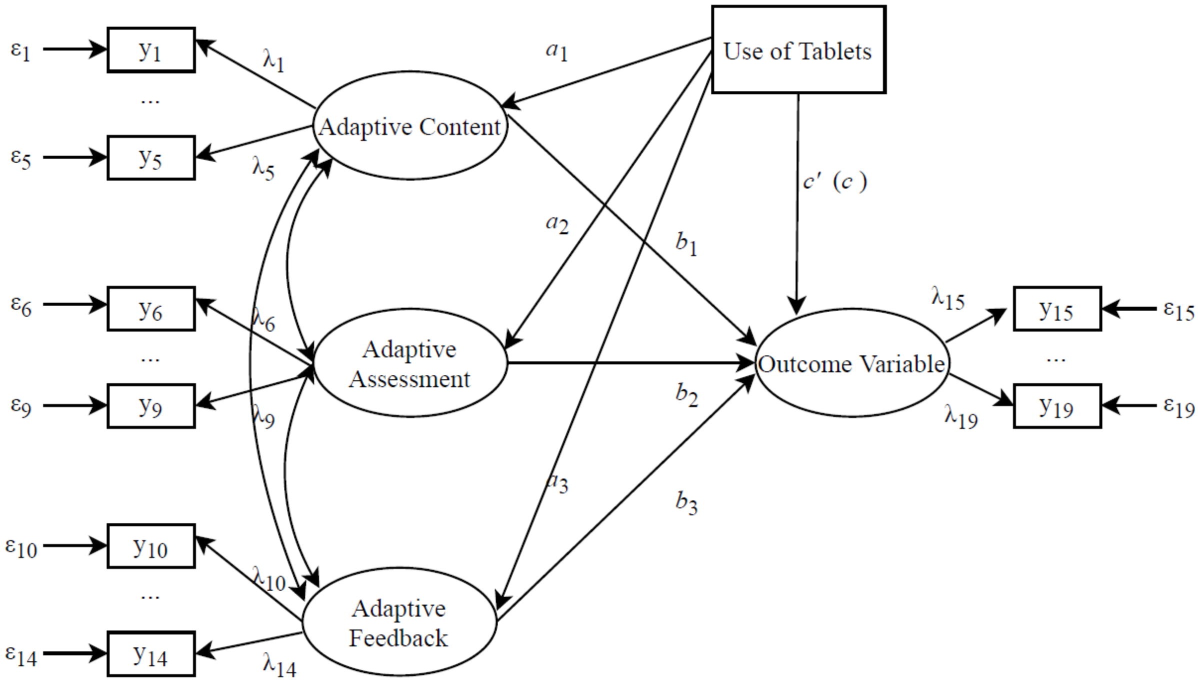
Estimations of the Three-Factor Confirmatory Factor Analysis for Adaptive Teaching

	Number of items	Factor loading	
		Unstandardized coefficient (*SE*)	Standardized coefficient (*SE*)
Adaptive content (AC)			
item 1	5	1.000 (fixed)	.893 (.005)
item 2		1.004 (.015)	.913 (.005)
item 3		0.993 (.016)	.889 (.005)
item 4		0.942 (.018)	.842 (.007)
item 5		0.946 (.018)	.836 (.007)
Adaptive assessment (AA)			
item 1	4	1.000 (fixed)	.820 (.008)
item 2		1.063 (.022)	.881 (.009)
item 3		1.056 (.022)	.874 (.006)
item 4		1.044 (.023)	.841 (.007)
Adaptive feedback (AF)			
item 1	5	1.00 (fixed)	.862 (.007)
item 2		0.999 (.017)	.903 (.005)
item 3		0.964 (.018)	.877 (.006)
item 4		1.037 (.020)	.863 (.007)
item 5		1.025 (.021)	.845 (.007)
Covariances			
AC with AA		0.555 (.022)	.830 (.009)
AC with AF		0.459 (.020)	.682 (.013)
AA with AF		0.458 (.020)	.761 (.011)

Note. This table is the supporting material of *Study 3*. The three-factor CFA model includes two cohorts' sample, $N = 2{,}286$. All the factor loadings are statistically significant ($p < .01$, two-tailed). The standard errors are shown in the parentheses. $\chi^2 = 454.84$, $df = 74$, $p < .001$; RMSEA = .05, 95% CI [.045, .054], CFI = .977, SRMR = .023

Appendix D2

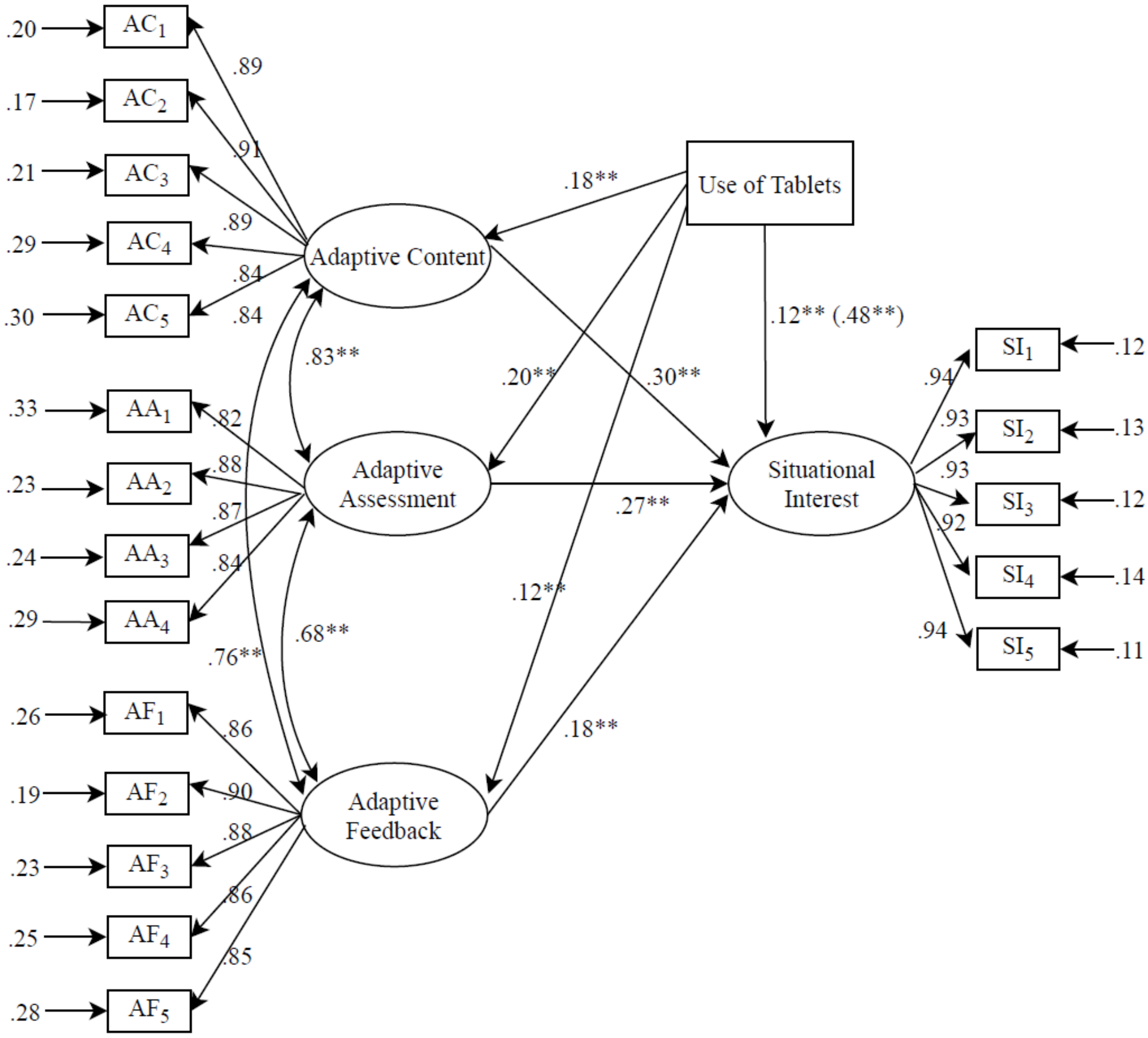
Hypothesized SEM of Mediation Analysis with Categorical Predictor Variable



Note. This is the hypothesized mediation model of *Study 3* (RQ2). In this model, a_i and b_i = indirect effects of the predictor variable (i.e., use of tablet computers) on the outcome variable. *c'* = direct effects of the predictor on the outcome variable. *c* = total effect of the predictor on the outcome variable in the non-mediated model.

Appendix D3

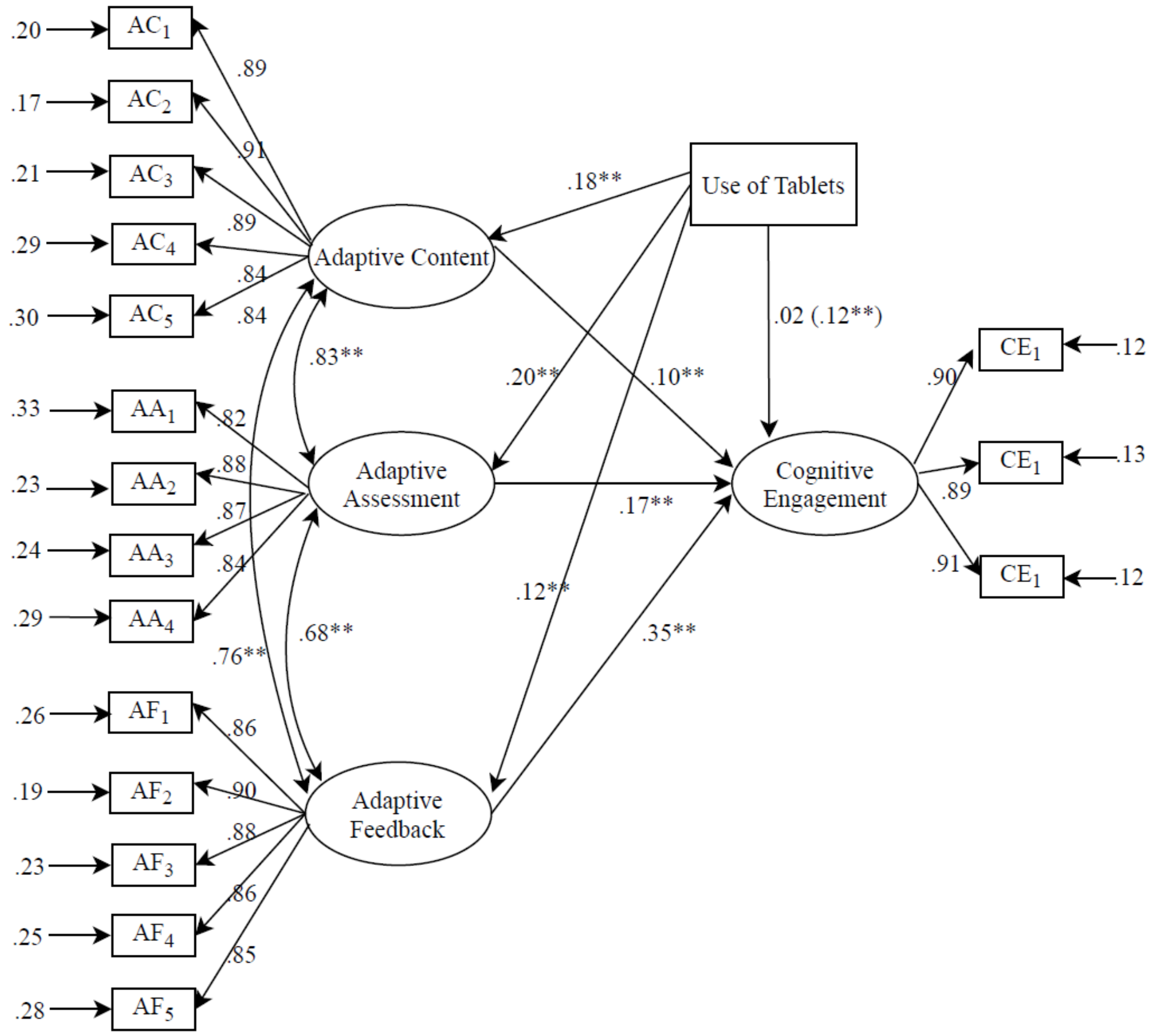
Estimations of Mediation Analysis with Situational Interest as Outcome Variable



Note. This figure presents the estimations of the mediation analyses in *Study 3* (RQ2). Goodness of model-fit: χ^2 = 1108.59, df = 161, p < .001; RMSEA = .05, 95% CI [.05, .06], CFI = .98, SRMR = .02.

Appendix D4

Estimations of Mediation Analysis with Cognitive Engagement as Outcome Variable



Note. This figure presents the estimations of the mediation analyses in *Study 3* (RQ2). Goodness of model-fit: $\chi^2 = 945.94$, $df = 126$, $p < .001$; RMSEA = .056, 95% CI [.052, .059], CFI = .976, SRMR = .021.

Appendix E1

Students' Use of Tablet Computers for Different Learning Activities in Mathematics Classes

Classroom activities	t_{11}			t_{12}		
	n	Not used	Used	*n*	Not used	Used
To make a PowerPoint presentation	598	381 (64%)	217 (36%)	488	274 (56%)	214 (44%)
To work with a learning program	599	64 (11%)	535 (89%)	488	117 (24%)	371 (76%)
To process text	593	497 (84%)	96 (16%)	487	429 (88%)	58 (12%)
To write text	594	491 (83%)	103 (17%)	485	423 (87%)	62 (13%)
To read a digital textbook	592	342 (58%)	250 (42%)	489	224 (46%)	265 (54%)
To calculate or work with databases	591	279 (47%)	312 (53%)	484	244 (50%)	240 (50%)
To organize learning materials	591	336 (57%)	255 (43%)	485	278 (57%)	207 (43%)
To play games	595	302 (51%)	293 (49%)	485	377 (78%)	108 (22%)
To draw graphs	596	299 (50%)	297 (50%)	487	280 (57%)	207 (43%)
To browse the Internet	594	351 (59%)	243 (41%)	487	291 (60%)	196 (40%)
To engage in online communication[a]	596	544 (91%)	52 (9%)	487	448 (92%)	39 (8%)
To do programming	594	506 (85%)	88 (15%)	487	435 (89%)	52 (11%)
To assess performance	591	393 (66%)	198 (34%)	486	329 (68%)	157 (32%)
To conduct simulations	592	421 (71%)	171 (29%)	486	332 (68%)	154 (32%)

Classroom activities (continue)	t_{11}			t_{12}		
	n	Not used	Used	*n*	Not used	Used
To do individual homework	592	121 (20%)	471 (80%)	485	155 (32%)	330 (68%)
To do group work	593	278 (47%)	315 (53%)	483	216 (45%)	267 (55%)

Note. The sample size for the tablet group was 721. *n* = numbers of participants who responded to the particular classroom activity. Not used = number of students who did not use the tablet computer for a particular classroom activity. Used = number of students who used the tablet computer for a particular classroom activity. Values in parentheses = percentage of students who used (did not use) tablet computers for the activity. [a] Examples of online communication are chats and forums.

Appendix E2

Overview of Tablet-Applications Used in the Mathematics Classrooms

Name of Application (summarized from the teachers' self-report)	Description	Academic subjects
Acrobat Reader*	To read and generate PDF document	General
Aufgabenfuchs Mathe*	To do online learning tasks; to prepare for the final examination; get corrective feedback immediately (flipped classroom)	Math
Adobe Spark Video	To create video and share online	General
BaiBoard*	Online collaborative whiteboard: use to create teaching content, to do web sharing and group work	General
BookCreator	To create eBook that blending the text, images, and multimedia	General
bettermarks	Adaptive mathematics textbooks and work sheets to support individual learners To assign text and tasks to secondary school students; provide automatic evaluation for the students' learning performance To provide teachers immediate statistics of students' answers	Math
BiBox 2.0 (Multimedia enriched e-book)	To provide level-differentiated materials enables optimal individual promotion The teacher is responsible for the material and decides which materials are available to particular student at specific time-period.	General
Digitaler Unterrichtsassistent Pro	To prepare and design lesson plan To provide student the work sheets with solutions and multimedia learning materials	General
Explain Everything	Collaborative Whiteboard	General

	Record information to create media-rich follow-ups, presentations, feedback, and meeting that can be shared immediately as streaming videos.	
EduPage	To organize online classes To provide digital textbooks To make annual curriculum plan To correct students' learning tasks	General
FlipaClip	Cartoon creator	General
Firefox*	Searching engine for surfing the Internet	General
Google Classroom*	To exchange data and do communication between teachers and students To do document management or taking note	General
GeoGebra*	To provide online mathematics tools (e.g., doing calculation, drawing) Online platform for exchanging ideas and educational materials	Math
GoodNotes*	To make notes and do document management	General
iMovie*	To create video	General
Keynote*	Presentation creator	General
Kahoot*	To create and play learning game, To do sharing and reinforcement	General
Kamara*	To take pictures	General
Kinemaster Pro*	Video clips creator	General
Klett eBook	To offer digital textbook, work sheets and solutions for students	General
Klett lernen	To provide additional material to the Klett eBook	General
Kstools*	Online mathematics tools: angle meter, calculator, barcode-/QR-Scanner	Math
Liveboard*	Interactive Whiteboard: to create, record and share classes online	General
Learning Snacks*	Do online quizzes and share educational materials	General

learningapps.com	Do programming	General
Mentimeter*	To create interactive presentation and meetings	General
MediaPlayer*	To play multimedia documents	General
Mathebattle*	To provide feedback To enhance transparency of requirements To strengthen the in-class cooperation	Math
Moodle*	To share educational materials online	General
Microsoft Office	To edit and manage documentation	General
MathGraph*	To draw graph by using common geometrical equations	Math
Mindmanager	To create mind map online To provide interactive communication	General
Numbers*	To make tables and do calculation,	Math
Number Line*	To do simulation for problem-solving tasks To do online calculation and measurement	Math
OneNote*	Document management and note-taking	General
Outlook*	Document management and communication	General
PDF Expert*	To read and generate PDF documents	General
PDF Creator*	To read and generate PDF documents	General
Pages*	To provide powerful word processing program that used to create impressive documents	General
PowerPoint*	To prepare presentation	General
Padlet*	To add teaching content, comment, and edits in real-time; To add photos, documents, video, music To share among classmates	General
popplet lite*	To create mind-map and visually organize the ideas	General
QR-Droid*	To read QR code	General
Quizizz*	To prepare self-paced quizzes to students, to review, assess, and engage student To provide personal feedback	General
Qrafter*	To read QR code	General
R compiler*	To do programming	Math

Scratch*	To create stories, games, and animations; To do online sharing among teachers, students, and parents	General
Scook Lernplattform	To provide digital textbooks and learning tasks	General
S-Note*	To take not	General
Simple mind*	To create mind map	General
Stage pro	To be used as interactive whiteboard To manage document	General
Socrative*	To do online quizzes, reporting, games, competition, evaluation, and provide feedback	General
Safari*	Searching engine for surfing the Internet	General
Book Creator*	To combine text, images, audio, and video to create interactive stories, digital portfolio, books, and reports	General
SPARKvue-Messwerterfassung*	To provide simplified data collection, visualization, and analysis application for STEM learning.	STEM
Scanner Pro*	To scan document	General
Stoppuhr*	Online timer	General
Teammaker*	To randomly group individuals into separate teams for classroom activities	General
Thinglink*	To create interactive images, videos, and media	General
TeacherTool*	To support teachers for grading, classroom management, and create lesson plans	General
Untis Mobile	To create and provide actual schedule with synchronized update	General
VLC media player	To play audio and video documents	General
Winkel*	To provide online protractor: to measure angle	Math
Wolfram Alpha*	Wiki platform: to provide information for mathematics, science, culture, and daily life	STEM
WPS Office*	To do document management and office work	General
XMind*	To create mind map online	General
YouTube	To watch online video	General

Note. The software and applications marked with asterisks are free for users.