Self-Regulated Learning in Digital Learning Environments in University and the Classroom: A Prerequisite and Improvable Competence for (Pre-Service) Teachers and Students

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"I saw as a teacher how,
if you take that spark of learning that those children have,
and you ignite it, you can take a child from any background
to a lifetime of creativity and accomplishment."

– Paul Wellstone, United States Senator from 1991-2002

"Education is the most powerful weapon
which you can use to change the world."

– Nelson Mandela, South African politician and activist

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List of Abbreviations

α	Alpha coefficient by Cronbach
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
AVE	Average Variance Extracted
β	Beta weight, regression coefficient
BIC	Bayesian Information Criterion
CFI	Comparative Fit Index
CG	Control Group
CI	Confidence Interval
COVID-19	Coronavirus SARS-CoV-2
d	Cohen’s d (effect size)
df	Degrees of Freedom
DGBL	Digital Game-Based Learning
E	Entropy
ed.	Edition
eds.	Editors
EG	Experimental Group
e.g.	exempli gratia (for example)
et al.	et aliter (and others)
F	Test value of the F-test
g	Hedge’s g (effect size)
GUESS	Game User Experience Satisfaction Scale
H	Hypothesis
I^2	I-squared value (heterogeneity)
κ	Cohen’s Kappa
LMRT	Lo-Mendell-Rubin Test
LPA	Latent Profile Analysis
M	Mean
Max	Maximum
Min	Minimum
η^2	Eta-squared (effect size)

N/n	Sample size
N_{fs}	Fail safe N
Q	Q-value (heterogeneity)
p	Probability
p.	Page
pp.	Pages (page X to page Y)
PEU	Perceived Ease of Use
PU	Perceived Usefulness
R^2	Variance explained
REML	Restricted Maximum Likelihood Estimator
RMSEA	Root Mean Square Error of Approximation
SD	Standard Deviation
SEM	Structural Equation Modeling
SPSS	Statistical Package of the Social Sciences
SRL	Self-regulated learning
SRMR	Standardized Root Mean Square Residual
SUS	System Usability Scale
STEM	Science Technology Engineering Mathematics
t	Test value of the t-test
τ^2	Between study variance in a meta-analysis
TAM	Technology Acceptance Model
χ^2	Test value of the Chi-test
z	Test value of the z-test

List of Publications

The present dissertation is based on four peer-reviewed journal articles. References of the full versions are in the appendix and available online through the respective journals.

Study I:

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2024). Students' Acceptance of E-learning: Extending the Technology Acceptance Model with Self-regulated Learning and Affinity for Technology. *Discover Education, 3*(114). https://doi.org/10.1007/s44217-024-00195-7.

Study II:

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2024). Fostering Self-regulated Learning in Pre-service Teachers Using Synchronous or Asynchronous Digital Learning Environments: A Latent Profile Analysis of Pre-Service Teachers' Individual Differences. *Frontiers in Education*, 9:1445182. https://doi.org/10.3389/feduc.2024.1445182

Study III:

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2024). The Evaluation of an Educational Game to Promote Pre-Service Teachers' Self-Regulated Learning. *Entertainment Computing, 52*, 100836. https://doi.org/10.1016/j.entcom.2024.100836

Study IV:

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2023). The Effect of Digital Game-Based Learning Interventions on Cognitive, Metacognitive, and Affective-Motivational Learning Outcomes in School: A Meta-Analysis. *Review of Educational Research, 94*(2), 193-227. https://doi.org/10.3102/00346543231167795

Summary

Future teachers can positively impact students' academic performance and future career success by fostering their future skills early on.

One of these future skills is self-regulated learning, which involves using cognitive, metacognitive, and motivational learning strategies to reach individual learning goals. When teaching self-regulation strategies, (future) teachers play a dual role. On the one hand, they act as self-regulated learners who serve as a model for their students by using these strategies themselves. On the other hand, they explicitly teach self-regulation strategies to their students in the classroom, creating learning opportunities that enhance self-regulated learning. To achieve this in the classroom, pre-service teachers must internalize the use of self-regulation strategies themselves and need to acquire knowledge of how to support their students' self-regulated learning.

Due to the Coronavirus (COVID-19) pandemic, digital learning environments have experienced an upswing and enable a wide range of applications for knowledge transfer. Accordingly, they are suitable for providing future teachers with the necessary skills and knowledge to promote self-regulated learning in their students. However, most digital learning environments are autonomous and already require self-regulation skills to use them effectively. While there is already a range of research looking at the effectiveness of digital learning environments, research into self-regulated learning in this domain, specifically for pre-service teachers, is still relatively new.

Therefore, this thesis aims to explore the dual role of self-regulated learning as a prerequisite for learning in digital learning environments and as a competence that digital learning environments can foster. Moreover, this thesis focuses on the target group of students, specifically pre-service teachers, in order to explore and promote their education through digital learning environments.

To use digital learning environments for learning, the technology must first be accepted by the learners. Based on the *Technology Acceptance Model*, Study I used a structural equation model to analyze the extent to which self-regulated learning influences the acceptance of e-learning and is, therefore, a prerequisite for learning in digital learning environments. The results show that self-regulated learning is an important factor for the acceptance of e-learning environments and is, thus, a prerequisite for learning in digital learning environments.

Since self-regulated learning is not only a prerequisite for learning in digital learning environments but can also be actively promoted by them, Study II dealt with the needs of pre-

service teachers in digital learning environments to improve the design of learner-oriented digital learning environments. However, there is still a lack of knowledge about individual differences in pre-service teachers' self-regulated learning, which is why latent profile analyses were used to gain further insights. The results support a three-profile solution for prospective teachers with low, moderate, and high self-regulation profiles. It was found that self-regulation training in digital learning environments is effective for prospective teachers with different self-regulation profiles, especially in terms of declarative knowledge, and beneficial in terms of strategy use, especially for those belonging to the low profile.

The research landscape has shown that pre-service teachers often have incomplete knowledge of self-regulated learning and, accordingly, have difficulties in teaching it directly to their students in the classroom. Since e-learning environments require a high degree of self-discipline and often have high drop-out rates, Study III used the innovative approach of digital learning games and developed an educational game specifically designed to promote pr-service teachers’ self-regulated learning. For an educational game to be effective, it must be highly user-friendly and contribute to a positive user experience. The aim of Study III was to evaluate the usability and user experience of the educational game *Regulatia* and to identify the prototype’s strengths and weaknesses. The results indicate that *Regulatia* is user-friendly and creates a positive user experience. The graphic design, the narrative, and the type of knowledge conveyed were identified as strengths. The text design, technical difficulties, and the scope and complexity of the content were identified as weaknesses.

Future teachers can also indirectly promote their pupils’ self-regulated learning by using suitable digital learning environments. Digital learning games offer an innovative way to teach students in the classroom. Previous meta-analyses have shown that digital learning games can have positive effects on learning at all education levels. However, the research of previous studies was limited to work conducted up to 2015. In the last five years, technological development has made rapid progress and opened up new possibilities. Digital learning games have become more accessible for teachers, and the number of electronic devices in schools has increased as a result of the digital transformation. Study IV, therefore, conducted a meta-analysis of the effectiveness of digital learning games in the school context between 2015 and 2020. In contrast to traditional learning techniques, the *Integrated Design Framework for Playful Learning* was used to investigate how well digital learning games affect cognitive, metacognitive, and affective-motivational learning outcomes. As metacognitive outcomes have never been investigated before, Study IV extends the research

to include this factor. The results show that using digital learning games in the classroom leads to better learning outcomes than conventional methods. A medium effect was found for cognitive learning outcomes, a small effect for affective-motivational outcomes, and no statistically significant effect for metacognitive learning outcomes. Furthermore, the effect of digital learning games was not significantly influenced by confounding, personal, or environmental moderators.

In summary, the present thesis contributes to research on self-regulated learning as a prerequisite for digital learning and as a skill that can be fostered in pre-service teachers.

Zusammenfassung

Zukünftige Lehrkräfte können positiv zur schulischen Leistung ihrer Schülerinnen und Schüler und damit zu einer guten Basis für eine spätere erfolgreiche berufliche Laufbahn beitragen, indem sie frühestmöglich deren future skills fördern. Einer dieser future skills ist das Selbstregulierte Lernen, welches den Einsatz kognitiver, metakognitiver und motivationaler Lernstrategien zur Erreichung individueller Lernziele beinhaltet. Bei der Vermittlung von Selbstregulationsstrategien nehmen (zukünftige) Lehrkräfte eine Doppelrolle ein. Zum einen sind sie selbst selbstregulierte Lernende, die durch ihren eigenen Strategieeinsatz als Modell für ihre Schülerinnen und Schüler dienen. Zum anderen können sie ihren Schülerinnen und Schülern explizit Selbstregulationsstrategien im Unterricht vermitteln sowie Lerngelegenheiten schaffen, die das Selbstregulierte Lernen stärken. Um dies im Unterricht leisten zu können, müssen angehende Lehrkräfte selbst den Einsatz von Selbstregulationsstrategien verinnerlichen und Wissen aufbauen, wie sie das Selbstregulierte Lernen bei ihren Schülerinnen und Schülern fördern können.

Aufgrund der COVID-19 Pandemie haben digitale Lernumgebungen einen Aufschwung erfahren und ermöglichen vielfältige Einsatzmöglichkeiten zur Wissensvermittlung. Dementsprechend sind sie geeignet, um zukünftigen Lehrkräften die benötigten Kompetenzen und das Wissen zur Förderung des Selbstregulierten Lernens bei ihren Schülerinnen und Schülern zu vermitteln. Allerdings sind die meisten digitalen Lernumgebungen autonom und erfordern bereits Selbstregulationsfähigkeiten, um diese effektiv nutzen zu können. Es existiert zwar schon eine Bandbreite an Forschung, die sich mit der Effektivität von digitalen Lernumgebungen beschäftigt, allerdings ist die Erforschung des Selbstregulierten Lernens in dieser Domäne und speziell für angehende Lehrkräfte noch relativ neu.

Deshalb ist das Ziel der vorliegenden Thesis, zum einen die Doppelrolle des Selbstregulierten Lernens als Voraussetzung für das Lernen in digitalen Lernumgebungen sowie als Kompetenz, die durch digitalen Lernumgebungen gefördert werden kann, zu erforschen. Zum anderen fokussiert sich die vorliegende Thesis auf die Zielgruppe der Studierenden und speziell auf angehende Lehrkräfte, um deren Ausbildung durch digitale Lernumgebungen zu erforschen und zu fördern.

Um digitale Lernumgebungen zum Lernen nutzen zu wollen, muss die Technologie von den Lernenden zunächst akzeptiert werden. Studie I analysierte auf Basis des Technology Acceptance Models mittels eines Strukturgleichungsmodells inwiefern das Selbstregulierte

Lernen einen Einfluss auf die Akzeptanz von E-Learning hat und dementsprechend als Voraussetzung für das Lernen in digitalen Lernumgebungen gilt. Die Ergebnisse zeigen, dass das Selbstregulierte Lernen einen wichtigen Faktor für die Akzeptanz von E-Learning Umgebungen darstellt und dementsprechend eine Voraussetzung für das Lernen in digitalen Lernumgebungen ist.

Da das Selbstregulierte Lernen nicht nur eine Voraussetzung für das Lernen in digitalen Lernumgebungen ist, sondern ebenfalls durch diese aktiv gefördert werden kann, beschäftigte sich Studie II mit den Bedürfnissen von angehenden Lehrkräften in digitalen Lernumgebungen, um die Gestaltung von lernerorienten digitalen Lernumgebungen zu verbessern. Es mangelt jedoch immer noch an Wissen über die individuellen Unterschiede im Selbstregulierten Lernen von angehenden Lehrkräften, weshalb latente Profilanalysen genutzt wurden, um weitere Erkenntnisse zu erlangen. Die Ergebnisse bestärken eine Drei-Profil-Lösung bei angehenden Lehrkräften mit einem niedrigen, moderaten und hohen Selbtregulationsprofil. Es zeigte sich, dass Selbstregulationstraining in digitalen Lernumgebungen für angehende Lehrkräfte mit verschiedenen Selbstregulationsprofilen vor allem in Bezug auf deklaratives Wissen effektiv ist und in Bezug auf Strategienutzung vor allem für Personen, die dem niedrigen Profil angehören, profitabel ist.

Die Forschungslandschaft hat gezeigt, dass angehende Lehrkräfte oftmals ein lückenhaftes Wissen über das Selbstregulierte Lernen besitzen und dementsprechend Schwierigkeiten haben, dieses direkt im Unterricht an ihre Schülerinnen und Schüler zu vermitteln. Da E-Learning Umgebungen ein hohes Maß an Selbstdisziplin erfordern und oft hohe Abbruchquoten verzeichnen, wurde in Studie III der innovative Ansatz von digitalen Lernspielen genutzt und ein Lernspiel entwickelt, welches speziell das Selbstregulierte Lernen von angehenden Lehrkräften fördern soll. Damit ein Lernspiel effektiv sein kann, muss es eine hohe Nutzerfreundlichkeit besitzen und eine positive Wahrnehmung bei den Nutzenden hinterlassen. Das Ziel von Studie III war die Evaluation der Benutzerfreundlichkeit und der Nutzererfahrung des Lernspiels *Regulatia* sowie die Ermittlung von Stärken und Verbesserungsmöglichkeiten des Prototyps. Die Ergebnisse deuten darauf hin, dass *Regulatia* benutzerfreundlich ist und ein positives Nutzererlebnis hervorruft. Als Stärken wurden die grafische Gestaltung, die Erzählung und die Art des vermittelten Wissens identifiziert. Als Schwächen wurden die Textgestaltung, technische Schwierigkeiten sowie der Umfang und die Komplexität der Inhalte identifiziert.

Zukünftige Lehrkräfte können das Selbstregulierte Lernen ihrer Schülerinnen und Schüler indirekt auch durch die Verwendung von geeigneten Lernumgebungen fördern. Digitale Lernspiele bieten eine innovative Möglichkeit, Schülerinnen und Schüler im Klassenzimmer zu unterrichten. Frühere Meta-Analysen haben gezeigt, dass digitale Lernspiele positive Auswirkungen auf das Lernen auf allen Bildungsebenen haben können. Die Forschung bisheriger Studien beschränkte sich jedoch auf Arbeiten, die bis 2015 durchgeführt wurden. In den letzten fünf Jahren hat die technologische Entwicklung rasante Fortschritte gemacht und neue Möglichkeiten eröffnet. Digitale Lernspiele sind für Lehrkräfte besser zugänglich geworden und die Anzahl der elektronischen Geräte in den Schulen hat im Zuge des digitalen Wandels zugenommen. In Studie IV wurde deshalb eine Meta-Analyse zur Wirksamkeit von digitalen Lernspielen im Schulkontext zwischen 2015-2020 durchgeführt. Im Gegensatz zu herkömmlichen Lerntechniken wurde basierend auf dem Integrated Design Framework for Playful Learning untersucht, wie gut sich digitale Lernspiele auf kognitive, metakognitive und affektiv-motivationale Lernergebnisse auswirken. Da metakognitive Ergebnisse noch nie untersucht wurden, erweitert Studie IV die Forschung um diesen Faktor. Die Ergebnisse zeigen, dass der Einsatz digitaler Lernspiele im Unterricht im Vergleich zu konventionellen Methoden zu besseren Lernergebnissen führt. Für kognitive Lernergebnisse zeigte sich ein mittlerer Effekt, für affektiv-motivationale ein kleiner Effekt und kein statistisch signifikanter Effekt zeigte sich für metakognitive Lernergebnisse. Weiterhin wurde die Wirkung der digitalen Lernspiele nicht signifikant durch konfundierende, persönliche oder umgebungsbedingte Moderatoren beeinflusst.

Zusammenfassend liefert die vorliegende Thesis einen Beitrag für die Erforschung des Selbstregulierten Lernens als Voraussetzung zum digitalen Lernen sowie als förderbare Kompetenz bei angehenden Lehrkräften.

1 Introduction

Future skills refer to the new set of abilities that are required for everyone to succeed in their work, education, and daily lives (Trilling & Fadel, 2009). Creativity, critical thinking, collaboration, and communication are often referred to as future skills that enable life-long learning (Voogt & Roblin, 2012). According to Graesser et al. (2022, p. 568), self-regulated learning (SRL) is another one of the future skills. SRL is a goal-directed process that enables people to strategically and purposefully control their thoughts, behaviors, and emotions in order to enhance learning. This competency is associated with life-long learning (Dent & Koenka, 2016) as well as increased academic achievement throughout all educational levels and grades (Xu et al., 2023).

On the one hand, SRL is a skill that can be developed through direct or indirect instruction. The dissemination of particular SRL strategies and knowledge through training programs run by qualified instructors is a common form of direct SRL promotion. In this instance, the students are conscious that they are studying SRL techniques specifically. A learning environment that allows for SRL but does not specifically instruct the use of SRL strategies is an example of indirect promotion, which is frequently unconscious (Dignath & Veenman, 2021).

On the other hand, in digital environments where learners frequently work independently, SRL is a necessary prerequisite for successful learning (Broadbent & Poon, 2015). Due to their frequent lack of interaction with lecturers, students must use SRL strategies to choose which learning resources to use at what time (Broadbent et al., 2021; Kizilcec et al., 2017). According to research, high SRL abilities increase a student's chances of success in online learning settings and uninterrupted assignment completion (Alhazbi & Hasan, 2021; Cho & Shen, 2013). Thus, it is important that SRL strategies are taught and used as soon as possible. Teachers at all school levels are crucial in helping students with SRL because it is not an automatic development (Dignath-van Ewijk, 2016). Teachers play a dual role in this regard: In order to support their students' SRL, teachers must be effective self-regulated learners as well as SRL agents (Backers et al., 2023; Karlen et al., 2020). To be effective educators, teachers must first learn how to be self-regulated learners themselves before learning how to assist students in doing the same (Karlen et al., 2023). Nevertheless, teacher education does not currently cover teachers' own SRL in a systematic manner, and pre-service teachers frequently do not develop it either. Teachers, as well as pre-service teachers, have difficulty implementing SRL (Dignath & Büttner, 2018). Some educators fail to engage and encourage their students' SRL abilities (Zohar & Ben-Ari, 2022). For instance, some pre-service teachers employ learning strategies mediocrely (Liu et al., 2020) and possess incomplete and inconsistent knowledge about SRL (Glogger-Frey et al., 2018; Granström et al., 2022). “Given the complexity of SRL and its implementation, teachers must have enough knowledge about the topic” (Backers et al., 2023, p. 4). Teachers must be able to justify different motivational, cognitive, and metacognitive SRL strategies before they can model or describe learning strategies. This requires an understanding of how SRL processes operate (Barr & Askell-Williams, 2019; Dignath & Veenman, 2021; Karlen et al., 2020). By using their experience as self-regulated learners, teachers can act as role models for their students and provide explanations for the strategies being used (Peeters et al., 2014). Additionally, teachers obtain a deeper comprehension of the learning experiences that their students have in SRL, which enables them to better identify and address the needs and challenges that students encounter in SRL. Through specific teacher training, SRL skills and their instruction to students can be enhanced (Michalsky, 2021). According to (Ng, 2015), digital learning environments offer students, and especially pre-service teachers, a flexible and ideal way to develop SRL strategies and create optimal learning conditions.

Digital learning environments have become an integral part of today's educational landscape. E-learning environments or digital learning games have suddenly gained popularity due to the COVID-19 pandemic and the accompanying remote learning. However, gaming on computers has always been more than just a hobby; educational games, in particular, are popular: As of July 28th, 2024, there were 267,406 apps in the *Google Play Store* and 191,698 in *the Apple Store* labeled with the category "education" (42matters, 2024). With the unexpected success of the game "*Pong*" and the release of the "*Atari*" console in the 1970s and early 1980s, there was a surge in research interest in video games. The late 1980s and early 1990s saw the emergence of innovative educational games that laid the groundwork for future educational games (Homer et al., 2020).

The German Federal Government, which has been funding the development of computer games with a maximum volume of 70 million euros annually since 2019, also recognizes the importance of computer games. As of December 2023, the federal government's computer game funding program has approved over 550 projects totaling over 200 million euros in funding. This program also supports the creation of learning games that have educational value (Federal Ministry for Economic Affairs and Climate Action, 2024).

Rapid technological advancements (faster internet, better computer hardware, virtual reality, etc.) have made various flexible options for knowledge transfer possible in digital learning environments. Thus, it is also possible to use digital learning environments to promote future skills such as SRL (Gurbuz & Celik, 2022; Thornhill-Miller et al., 2023).

Thus, the main objective of this thesis is to investigate SRL in digital learning environments, emphasizing how it functions as both an improvable competency and a prerequisite for digital learning. Three empirical studies with university students and pre-service teachers and a meta-analysis focusing on the school context were conducted to meet the thesis's objective.

Study I focused on SRL's contribution to students' technology acceptance as a prerequisite for digital learning. The goal of Study I was to integrate SRL as a necessary precondition and, consequently, an external factor for successful e-learning into the *Technology Acceptance Model* (TAM, Davis, 1989). There is currently insufficient research on evaluating SRL's component structure in TAM, which adds to the body of evidence supporting its significance in technological adoption.

Study II concentrated on pre-service teachers' roles as self-regulated learners because SRL is not only a prerequisite for learning in digital learning environments but also a promotable competence. In order to better understand how to enhance pre-service teachers' SRL, the study examined the SRL profiles of pre-service teachers in two distinct digital learning environments. By investigating this, the study advances the development of recommendations for the creation of learning environments that provide users with adaptive learning opportunities and advances research into the differing effects of learning in digital learning environments on pre-service teachers.

Study III offers a potentially more engaging method of preparing pre-service teachers to teach SRL strategies through a digital educational game since (pre-service) teachers are also agents of SRL. The study assesses the usability and user experience of the game’s first functional prototype, which may have an impact on its success (Boulay et al., 2011). First, we examined how user-friendly the game is thought to be. In order to further refine the prototype, we evaluated how learners perceive the various game elements and gathered the game's advantages and disadvantages.

While Study I focused on SRL as a prerequisite for learning in digital learning environments, Studies II–III concentrated on the role pre-service teachers played in promoting SRL in digital learning environments. Study IV sought to determine how well students responded to game-based learning in a classroom setting. The usefulness of educational games for students is unknown because the majority of studies concentrate on student populations. To gain insight into whether educational games are appropriate for teaching students, a meta-analysis was conducted based on the *Integrated Design Framework for Playful Learning* (Plass et al., 2015).

2 Theoretical Background

The primary concepts of this thesis will be reviewed and defined in this section, with empirical evidence to back them up. The emphasis will be on pre-service teachers as a special group. The first section will give an overview of SRL and discuss how it relates to academic success. Following this, the dual role of SRL is discussed as both a prerequisite and competence that can be promoted in digital learning, especially in relation to pre-service teachers and their challenges in digital learning environments. Subsequently, the thesis focuses on digital learning through e-learning and digital game-based learning (DGBL) and presents its effectiveness. The current thesis then derives its research questions from the theoretical framework.

2.1 Self-Regulated Learning

By providing a definition for SRL in the first step, this section presents one of the central constructs of this thesis. Second, a description of the theoretical models that served as the foundation for the research is given. The connection between learning achievement and SRL is discussed in the third section, and its importance for pre-service teachers is emphasized in the final section.

2.1.1 Definition

Firstly, it is important to differentiate between self-regulation and SRL in order to fully understand the complexity of the concept. Self-regulation, based on Bandura’s social-cognitive theory (1986), involves establishing goals, maintaining them, and adjusting to changes in situations. The focus is on adaptively working towards goals, as highlighted in Zimmerman's (2000) definition that self-regulation includes “self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals” (p. 14). In order to practice self-regulation, learners must control their thinking, sensations, and behavior. The definition demonstrates cyclical adaptation, implying a process-oriented perspective. It is necessary to evaluate previous actions to adjust to shifting environmental features and maximize the application of suboptimal strategies.

If an individual self-regulates their learning process or applies it in an academic context, it is referred to as self-regulated learning (Zimmerman, 2008). SRL is defined as “a process whereby learners activate and sustain cognitions, affects, and behaviors that are systematically oriented towards the attainment of personal goals” (Zimmerman, 2011, p. 1). This definition highlights important aspects also found in other definitions of SRL: learner autonomy in organizing, executing, and reflecting on their learning process. According to Zimmerman (2008), SRL is a proactive process that necessitates a high level of implementation of SRL strategies. Moreover, it is a broad interdisciplinary skill that aids students in devising, executing, and scrutinizing their learning procedures and functions across diverse disciplines (Bembenutty, 2011). SRL can include both different phases and different components, which are further described in the next section.

2.1.2 Theoretical Models of Self-Regulated Learning

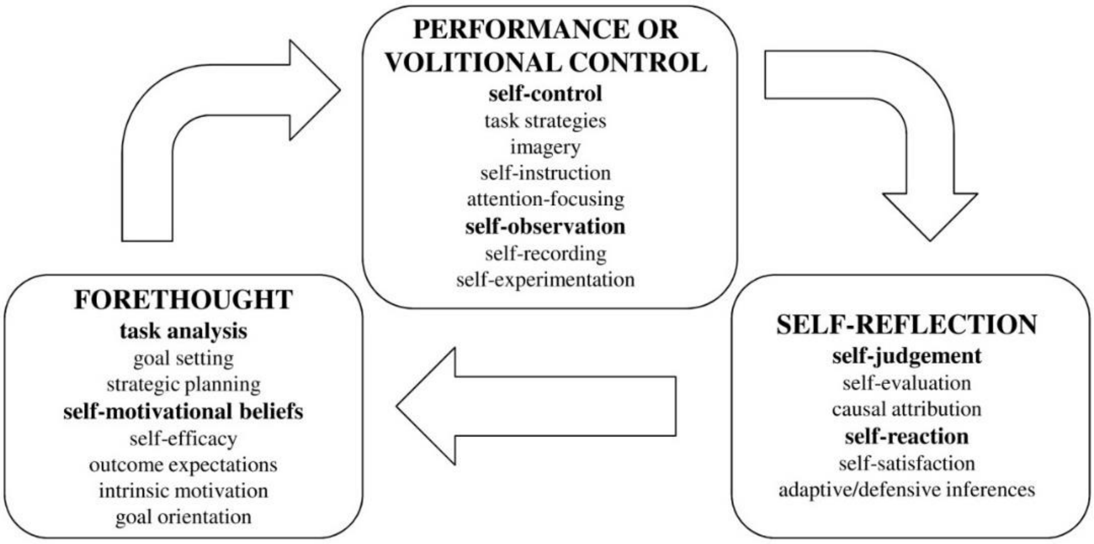
Several theoretical models describe SRL, distinguishing between component and process models. Component models concentrate on the individual SRL competence, comprising cognitive, motivational, and metacognitive components: Conceptual and strategic knowledge, as well as the capacity to use the right learning techniques, are examples of the cognitive component. Activities that both start and maintain learning are examples of the motivational component. Planning, self-monitoring, and reflecting on the learning process represent the metacognitive component (Boekaerts, 1999). Instead of breaking down SRL into different components, Zimmerman’s (2000) social cognitive model of SRL classifies the learning process into discrete phases that correspond to the essential elements of SRL, characterizing SRL as a cyclical process. Zimmerman's (2000) model, which is the foundation for the interventions in the current thesis, is the most widely used model for intervention studies because it considers the various components of SRL and its circularity (Panadero, 2017). According to the model, learning occurs in three phases: forethought, performance, and self-reflection (see Figure 1). These consist of motivational, cognitive, and metacognitive elements. The phases of SRL occur sequentially, and future strategies are influenced by past learning processes, giving rise to its cyclical nature. The first stage of learning is referred to as the "forethought phase". It acts as preparation for learning and for carrying out actions. Learning is a goal-oriented process where learners first identify what they want to achieve.

They then set goals and choose learning strategies that seem to help them achieve those goals. During this process, existing knowledge and past experiences are used to select appropriate learning strategies and behaviors to plan the next steps. If the learners believe they can accomplish the task with the available resources, it boosts their motivation at the beginning of the action.

Learning happens during the performance phase. In this stage, newly learned information is reinforced using cognitive strategies like repetition. Motivational strategies are crucial to sustaining the learning process during this phase. Learning can proceed only when students can sufficiently motivate themselves and possess sufficient volitional strategies to block out distractions and focus their attention (Alhazbi & Hasan, 2021; Valenzuela et al., 2020). Learners are required to exercise self-control so they can modify their strategies as needed during the entire learning process. One crucial metacognitive technique that helps students modify their learning behavior when there is a mismatch between their objectives and their present situation is self-observation (de Bruin & van Gog, 2012). Through self-monitoring, students pinpoint the instructional approaches that have not worked as well and should be dropped. In the subsequent "self-reflection phase", students compare their goals from the forethought phase with their actual performance to conducting a self-evaluation. This comparison involves choosing effective strategies for future learning, rejecting ineffective strategies, and/or modifying objectives because the original ones proved unachievable (Zimmerman, 2000). Because of this, students need to be able to assess their performance, which is directly related to causal attribution (Brun et al., 2021). An internal variable attribution would be the best choice for SRL since it helps students feel more accountable and in control of their learning. There are various options for how the learning outcomes can be reacted to by oneself. Higher levels of self-efficacy in learners have been found to arise from self-satisfaction with one's abilities. Overall, the learner's self-motivational beliefs and outcome expectations are solidified by the successful completion and positive evaluation of a task. This results in positive emotions, such as pride, influencing the strategies chosen during the proximate forethought phase (Zimmerman, 2000).

Figure 1

Process Model of Self-Regulated Learning



Note. Model adapted from Zimmerman, 2000.

2.1.3 Self-Regulated Learning and Achievement

SRL is a factor in lifelong learning (Dent & Koenka, 2016) and positively correlates with improved learning outcomes across all educational phases (Xu et al., 2023). According to Zimmerman and Schunk (2011), students with SRL skills can outperform their peers by utilizing their unique thinking potentials and motivation in conjunction with improved resource and environment management. When it comes to using SRL strategies, high achievers are more successful than low achievers (Zimmerman, 2002). For example, time management techniques assist students in avoiding procrastination and completing assignments and projects on time (Lewis & Oyserman, 2015). As students actively control their learning, they are more likely to use effective cognitive strategies that lead to improved learning and higher academic attainment (Jansen et al., 2019). Numerous studies have provided empirical evidence to support the positive relationship between SRL and academic achievement (e.g., Khan et al., 2020; Kizilcec et al., 2017; Yamada et al., 2017).

For elementary and secondary school children, the meta-analysis by Dent and Koenka (2016) found a significant correlation between academic performance and cognitive strategies as well as metacognitive processes. When it comes to metacognitive processes—which assist students in controlling their own learning and academic performance—the correlation is especially strong.

For university students, Theobald (2021) performed a meta-analysis, concluding that SRL training programs had a positive impact on academic performance, SRL strategies, and motivation.

For the special group of pre-service teachers, Vosniadou et al. (2021) confirmed a positive correlation between academic achievement and cognitive and metacognitive strategies in a study involving 366 pre-service teachers.

The findings hold true for blended and online learning settings as well. In online and blended learning environments, learners in elementary, secondary, postsecondary, and non-formal adult education settings demonstrated a positive and moderate effect of SRL intervention, according to the meta-analysis by Xu et al. (2023).

The benefits of SRL extend beyond the classroom as students gain confidence and prepare for obstacles and changes in their academic and professional lives through a variety of self-regulatory and lifelong introspective as well as reflective processes (Lent et al., 2019). This enables a smooth transition from education to employment (Hsu et al., 2022).

It is crucial that students should develop SRL as early as possible because of the several mentioned benefits of SRL on achievement (Cleary & Russo, 2023). Teachers have a particularly great responsibility in this regard and can introduce their pupils to SRL at an early stage.

2.1.4 Relevance of Self-Regulated Learning for (Pre-Service) Teachers

Teachers are vital in helping their students develop their sense of SRL, but they also need the ability to help students develop SRL skills. There are several ways that teachers can support pupils' SRL development, e.g., by assigning challenging tasks, letting them make their own decisions, or giving them chances to reflect on their work (Dignath & Veenman, 2021). In addition to directly imparting knowledge to their students, teachers act as role models by utilizing SRL strategies themselves (Peeters et al., 2014). Because of this, they are crucial in assisting students in learning SRL concepts and practical application techniques. Buzza and Allinotte (2013) state that teachers with strong SRL competencies are more likely to comprehend the ideas behind encouraging SRL. Furthermore, research by Gordon et al. (2007) demonstrated that teachers with strong SRL competencies are more likely to foster a mastery-oriented learning environment in the classroom, supporting students' SRL.

Additionally, it is believed that self-regulated learners are capable of applying a range of cognitive, motivational, and metacognitive strategies, allowing pre-service teachers to adapt their approaches in order to complete academic assignments more successfully (Fuchs et al., 2022). Consequently, pre-service teachers need to develop their own self-regulated learning in order to support their students' SRL.

According to research, pre-service teachers frequently have a disorganized and fragmented understanding of SRL strategies (Lawson et al., 2019; Ohst et al., 2015). Additionally, according to Glogger-Frey et al. (2018), some pre-service teachers exhibit poor metacognitive strategy knowledge, which makes it difficult for them to teach SRL strategies. Research has additionally indicated that pre-service teachers are not well-versed in SRL regarding teaching strategies that support metacognition (Zohar & Ben-Ari, 2022). For pre-service teachers to consider SRL an essential part of their professional identity, they need to be well-informed about it (Fuchs et al., 2022).

Successful learners employ effective learning strategies to accomplish their objectives; they do not use more SRL strategies but rather a greater variety of them than less successful learners (Perry et al., 2018). Studies reveal that pre-service teachers do not strongly engage in SRL during their studies (Fuchs et al., 2022). They also seldom spontaneously use SRL strategies (Engelmann et al., 2021) and generally utilize few SRL strategies to manage their learning (de Bruin & van Merriënboer, 2017). Pre-service teachers often use ineffective strategies (Fryer & Vermunt, 2018; McDaniel & Einstein, 2020) and struggle to integrate various SRL skills to tackle learning challenges (Karlen & Hertel, 2024). According to León et al. (2023), some pre-service teachers either overestimate or underestimate their self-regulated learning abilities, while others hold misconceptions about it (Karlen & Hertel, 2024). In line with these results, Lawson et al. (2019) hypothesized that pre-service teachers might not be aware of the benefits of their SRL strategies and, as a result, either not use them at all or stop using them too soon. Pre-service teachers are seldom taught effective strategies during their studies, and they frequently only use a few particular strategies in their teaching later on (Dignath & Büttner, 2018). Consequently, some pre-service teachers fail to help their students develop their SRL skills and activate them (Spruce & Bol, 2015; Zohar & Ben-Ari, 2022). Since SRL skills help pre-service teachers improve their academic performance and prepare them to assist their students with SRL skills in the classroom, it is important to promote SRL among pre-service teachers at an early stage.

2.2 Digital Learning

This section presents the second central construct of this thesis. Definitions for e-learning and DGBL as digital learning environments are given. Later on, their effectiveness is demonstrated with empirical evidence.

Generally, digital learning is learning that occurs in specifically designed digital learning environments. Digital learning environments are platforms or apps that offer course materials, allowing learners to study remotely at their own pace with or without guidance from an instructor (Arguel et al., 2017; Kümmel et al., 2020). Research currently available indicates that digital learning environments can enhance learning by motivating learners (Chang et al., 2017). In addition, they have the benefit of reaching many individuals at the same time. According to Broadbent et al. (2020), digital learning environments are especially well-suited for teaching interdisciplinary skills, e.g. SRL, because they allow students to work on them at any time and from any location. In the present thesis, e-learning and DGBL are the focus of the investigation. Therefore, the following sections describe both digital learning environments in detail.

2.2.1 E-Learning

Electronic learning is referred to by its acronym, e-learning, for which there is currently no standard definition. It is widely agreed upon that digital media is a component of e-learning when examining its attributes. This could be a variety of educational resources, like audio, text, or video. The content can be delivered through asynchronous communication, in which teachers and students are not online at the same time, such as through quizzes, assignments, or forums, or synchronous communication, in which students and teachers are online at the same time, such as through live chat or video conferences (Shahabadi & Uplane, 2015). According to Clark and Mayer (2016), e-learning is every “instruction that is delivered on a digital device that is intended to promote learning” (p. 7). E-learning environments are characterized by Johnson and Davies (2014) as networked because they are accessible to users through computers equipped with standard internet technology, allowing for instantaneous updating, storing, and retrieving information, distributing it, and sharing it. Learning management systems represent one common type of e-learning environment. Higher education saw an increase in the use of e-learning as a learning technology due to the COVID-19 pandemic's forced online learning. As a result, e-learning settings and the technological potential for online learning both improved. With the range of task types available in modern e-learning environments, instructors can design independent learning experiences that may promote self-regulated learning.

2.2.2 Digital Game-Based Learning

E-learning environments have a disadvantage in that the rate of students dropping out is relatively high (Lee & Choi, 2011). To encourage learning, a current approach by educators is to combine games and learning. According to Salen and Zimmerman (2004), a game is “a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome” (p. 5). Until now, there has been no consensus on a universal definition of games, which is why they are often described by their characteristics. Games are based on predetermined rules and regulations. They can react to the player's actions by giving appropriate feedback. In games, a player's advancement is cumulative, and they are made to be difficult, frequently with a chance component. For this reason, playing games can be a very motivating experience for players, pushing them to participate fully in the game. Learning with games was defined as “any marriage of educational content and computer games” by Prensky (2007, p. 145), who strongly affected the term “digital game-based learning”. In the beginning, the definitions for DGBL were rather unspecific, for example, Moreno-Ger et al.'s (2008) definition as “any initiative that mixes videogames and education can be considered as game-based learning” (p. 2). Over the years, the goal of advancing teaching and learning processes became increasingly central to DGBL definitions. When digital games are expressly “designed and used for teaching and learning”, according to Al-Azawi et al. (2016, p. 132), we can refer to them as DGBL. According to Plass et al. (2020), learning games must provide clear learning objectives. Cojocariu and Boghian (2014) emphasized the integration of mobile devices (e.g., tablets and smartphones) with educational content as a feature of DGBL. Additionally, applying new digital technologies may promote a cognitive shift and add entertainment value to the learning process, enhancing learning (Khan et al., 2017).

Erhel and Jamet's comprehensive definition of DGBL encapsulated earlier theories defining it as “a competitive activity in which students are set educational goals intended to promote knowledge acquisition. The games may either be designed to promote learning or the development of cognitive skills, or else take the form of simulations allowing learners to practice their skills in a virtual environment” (Erhel & Jamet, 2013, p. 156). This definition highlights the objective of promoting learning processes and takes the part of practicing specific skills into consideration. Summing up the previous definitions, DGBL is characterized by the use of mobile devices to apply digital games that deliver educational content for learning following determined learning objectives.

Given that DGBL and associated terms are often used interchangeably, a differentiation is made in the following. The term "serious games" is often used in connection with DGBL and is defined as "games that do not have entertainment, enjoyment, or fun as their primary purpose" (Michael & Chen, 2006, p. 21). A clear categorization of serious games is not always possible. This is why Marsh (2011) suggested viewing serious games as a continuum that includes games with a purpose on the one end and experimental environments with almost no gaming characteristics at the other end. Serious games can, therefore, be used as a tool in DGBL but are not exclusively designed for learning.

The term "gamification" is associated with DGBL and is defined as "the use of game design elements in non-game contexts" (Deterding et al., 2011, p. 2). Gamification only uses one or two game elements to boost player engagement, and the tasks remain essentially unchanged, whereas DGBL applies complete games to engage learning (Becker, 2021), and tasks must be redesigned to make them more engaging (Plass et al., 2020).

2.2.3 Effectiveness of Digital Learning

Digital learning environments have the potential to improve learning outcomes (Clark et al., 2016), such as by motivating students (Chang et al., 2017) because according to the Self-Determination Theory, they satisfy human basic needs, namely autonomy, relatedness, and competence (Ryan & Rigby, 2020). E-learning environments and in-person instruction only marginally differ from one another regarding knowledge impartation and achievement, according to a meta-analysis conducted by Bernard et al. (2004). This study also indicates that blended learning environments—which combine online and in-person instruction—are slightly better regarding knowledge impartation. E-learning is another efficient teaching strategy that is on par with traditional learning (Cook, 2009) and other forms of medial learning (Bell & Federman, 2013).

According to a growing body of research (Lei et al., 2022), DGBL interventions enhance knowledge acquisition, skill development, and learning outcomes through the creation of more engaging and interesting instructional tasks compared to traditional methods. Future skills such as communication (Plass et al., 2020), critical thinking (Mao et al., 2021), problem-solving, and teamwork (Martín-Hernández et al., 2021) can all be enhanced by educational games. They also encourage and support mental activity (Mayer, 2014).

Additionally, educational games can emotionally impact learners (Loderer et al., 2020) and offer chances for meaningful social interactions (Plass et al., 2020). This means educational games enhance cognitive, affective, motivational, and behavioral engagement.

What makes educational games special is that they have the ability to enable so-called graceful failure. Failure adds interest to the game and is occasionally essential for learning. Additionally, graceful failure can encourage chances for self-regulated learning, enabling participants to assess the efficacy of their tactics and the degree to which their objectives have been met (Plass et al., 2020).

Furthermore, educational games allow the safe practice of new abilities. For example, medical training simulations enable the practice of specific surgical techniques without endangering patients (Fens et al., 2021). In other words, digital learning makes it possible to practice and reinforce already acquired knowledge and skills in addition to learning new ones.

This makes educational games suitable for use throughout various areas (e.g., healthcare, STEM, engineering, language learning, and history; Hartt et al., 2020). The most commonly examined outcomes are motivation, social interaction, and learning achievements, with educational games positively impacting these aspects (Kalogiannakis et al., 2021).

Educational games can benefit all learner groups, from preschool to university (Tsai & Tsai, 2020), which indicates the broad effect of DGBL on students' academic achievement (Clark et al., 2016; Karakoç et al., 2020; Mayer, 2014). Regarding learning achievement, DGBL seems especially effective for specific content domains such as language learning (Acquah & Katz, 2020) and science (Mayer, 2014).

This is also supported by the findings of McLaren et al. (2017), who showed that a math game led to better performance in a math test than in a control condition without a game. Siuko et al. (2024) came to a similar conclusion for high school students who were given a web-based game on graph reading. Following DGBL interventions for language learning, there have also been increased learning gains (e.g., higher test scores; Franciosi, 2017).

To sum up, digital learning environments, such as e-learning and educational games, are suitable for acquiring new knowledge and future skills as well as for practicing already existing skills.

2.3 Self-Regulated Learning as a Prerequisite for Digital Learning

There are differences between learning in analog and digital environments. Within digital learning environments, learners must use SRL strategies to choose which learning materials to engage with and when, as they frequently have limited interaction with lecturers (Broadbent et al., 2021; Kizilcec et al., 2017). To succeed in digital learning environments, students must exercise this autonomy by organizing, supervising, and assessing their learning process. In addition, students must maintain their motivation to finish the entire online course (Broadbent & Poon, 2015).

Studies have indicated that learners with self-regulation abilities are more likely to be successful in online learning settings and finish assignments without interruption (Alhazbi & Hasan, 2021; Ning & Downing, 2015). According to Ainscough et al. (2019), learners who exhibit high levels of self-regulation tend to complete tasks in digital learning environments at a higher rate.

Self-regulated learners are able to plan and choose appropriate learning strategies and comprehend the learning environment and tasks more quickly due to their prior knowledge and experience (Johnson & Davies, 2014). Additionally, it is assumed that self-regulated students possess the ability to apply a range of motivational, metacognitive, and cognitive SRL strategies. These students can use a variety of SRL strategies to complete their assignments on time (Fuchs et al., 2022; Taub et al., 2020). In digital learning environments, time management, critical thinking, and the application of metacognitive strategies have been shown to be especially effective in improving learning outcomes (Broadbent & Poon, 2015). Self-regulated students welcome new challenges, grow from their errors, and persevere through setbacks when learning online (Karlen & Hertel, 2024). Additionally, they have improved navigational skills in digital learning environments. To navigate digital educational games, "students must enact several metacognitive processes, such as monitoring, planning, and selecting effective learning strategies" (Taub et al., 2020, p. 249). In digital learning environments that are more open-ended and require learners to take greater control over their learning process, SRL is particularly crucial. For example, in order to finish a digital educational game successfully, students can ask themselves if they have previously finished a task similar to this one or seek assistance and scaffolding from a non-player character (Loderer et al., 2020).

As the earlier justifications demonstrate, SRL is a crucial factor in effective learning in digital learning environments.

2.4 Fostering Self-Regulated Learning with Digital Learning Environments

SRL plays an important role in digital learning environments. This role can be seen in two ways: On the one hand, SRL is an essential prerequisite for successful learning in digital learning environments, and on the other hand, relevant research indicates that SRL can be fostered using digital learning environments (van der Beek et al., 2021). This section emphasizes the importance of SRL as a skill that can be developed. It discusses the distinction between direct and indirect training and the role of (pre-service) teachers in teaching and promoting SRL. Subsequently, the promotion of SRL through e-learning and DGBL with supporting evidence is presented. Finally, the thesis provides insight into how to transfer the promotion via DGBL in the school context.

2.4.1 Direct and Indirect Training

One can directly or indirectly promote SRL as a competency (Dignath & Büttner, 2018). One common method of direct promotion is using training programs run by qualified instructors to impart particular SRL strategies and knowledge. In this instance, the students know they are explicitly learning SRL strategies. Providing a learning environment that allows for SRL without specifically instructing SRL strategies is one example of indirect promotion, which is frequently unconscious (Dignath & Veenman, 2021).

Teachers can help students develop SRL skills using various instructional strategies (Dignath-van Ewijk, 2016). By giving students information about a learning strategy, such as how, when, and why to use it, they can directly train SRL (Dignath & Veenman, 2021).

By assigning students a task that necessitates the application of a specific strategy without explicitly stating that it may be an effective learning strategy or by modeling the use of a strategy without disclosing to the students any information about the strategy, teachers can subtly encourage students to act as self-regulated learners (Dignath & Veenman, 2021). Backers et al. (2023) suggest that creating a challenging, complex, task-filled learning environment that prompts students to evaluate themselves and gives them meaningful choices and clear goals can also be used to achieve indirect instruction of SRL. Only a small percentage of teachers give students direct instruction, which causes them to concentrate primarily on teaching cognitive strategies and pay little attention to teaching metacognitive strategies, according to Dignath and Veenman's review study (2021), which only included classroom observation studies. Compared to direct instruction, indirect instruction of SRL is used more frequently, and primary school teachers are more likely than secondary school teachers to create learning environments that foster students' SRL skills (Dignath & Büttner, 2018).

Through direct and indirect training methods, teachers and pre-service teachers can support their students’ development of SRL in the classroom. Therefore, they are crucial for their students’ SRL and can function as multiplicators for SRL.

2.4.2 (Pre-Service) Teachers’ Role as a Multiplicator of Self-Regulated Learning

It is essential to remember that SRL skills do not develop automatically; they have to be learned. According to Backers et al. (2023), teachers are essential to support students who are having difficulty with SRL. Before being able to help students develop SRL skills, teachers must first develop their own proactive and self-regulatory learning skills (Kramarski, 2017). Teachers who practice self-regulation as learners are conscious of their own learning strengths and weaknesses, employ various strategies, and know when, how, and where to use them (Karlen et al., 2023). To specifically support cognitive, metacognitive, and motivational SRL strategies in their students, teachers must first become knowledgeable about SRL and understand how the self-regulation process functions (Karlen et al., 2020). Studies indicate that teachers possessing a strong understanding of SRL can effectively implement both direct and indirect teaching methods, such as elucidating the appropriate timing of a strategy or establishing effective SRL learning environments to enhance their pupils' SRL (Dignath & Veenman, 2021). Higher SRL proficiency among teachers makes them feel more confident about promoting SRL, which makes them more likely to use it in the classroom. Additionally, teachers obtain a deeper comprehension of the learning experiences that their students have in SRL, which enables them to identify better and address the needs and challenges that students encounter in SRL (Karlen et al., 2023).

Teachers are multiplicators of SRL because of the various roles they play in its promotion. They plan their lessons with the goal of ensuring that their students comprehend the content (Johnson & Davies, 2014) and can apply SRL principles directly to the curriculum (Karlen et al., 2021). During class, teachers are instructors and explicitly explain SRL strategies and when they can be used effectively (Karlen & Hertel, 2024). Moreover, teachers can also help students during their SRL process by stepping in if needed or offering extra assistance, like partial solutions. Teachers also offer emotional support throughout the process because it takes time for SRL to develop and for strategy use to be applied (Johnson & Davies, 2014). They serve as role models as well. By modeling SRL behaviors, teachers motivate students by setting a positive example (Karlen & Hertel, 2024; Peeters et al., 2014).

However, teacher education does not currently cover teachers' own SRL in a systematic manner, and pre-service teachers frequently do not develop it during their studies (Glogger-Frey et al., 2018). When it comes to specifically addressing pre-service teachers' SRL skills, it seems imperative to concentrate on improving their knowledge and beliefs on SRL. As mentioned in Chapter 2.4, SRL can be promoted with training interventions (Michalsky, 2021) and especially by using digital learning environments.

2.4.3 Fostering Self-Regulated Learning with E-Learning in Higher Education

E-learning environments are digital learning environments that can be used to promote SRL directly and indirectly. According to research, students receiving SRL training may perform better academically and frequently employ SRL strategies (Kramarski & Michalsky, 2010). Although traditional learning environments still host the majority of SRL training, there is mounting evidence that digital learning environments can also effectively promote SRL. However, randomized controlled SRL online trainings are still limited. The most common SRL training approach is the direct conveyance of SRL strategies.

Van der Beek et al. (2021) and Bellhäuser et al. (2016) conducted two direct SRL e-learning trainings for students, supporting the findings that classroom seminars and e-learning are equally effective in promoting SRL. In a study by Broadbent et al. (2020), a discipline-independent SRL training intervention was implemented using a mobile diary app. The aim was to assess the impact of SRL online learning intervention on university students. The study involved $N = 73$ university students, with 16 students receiving online training, 21 using the mobile app diary, 14 receiving a combination of online training and app usage, and 22 in the control group. The online training lasted for three sessions, each lasting 60-90 minutes, over 21 days. The measures utilized to assess the intervention consisted of a knowledge test, the Motivated Strategies for Learning Questionnaire, and a learning diary that encompassed SRL intention, use, and affect. The results showed that the combined group (online training plus app) outperformed the other groups regarding knowledge, elaboration, organization, critical thinking, time management, metacognition, and effort regulation. The online training alone improved control beliefs compared to the control group. The combined group reported higher SRL intention and use than the other groups. These studies obtained promising results in terms of course performance, knowledge of SRL, and its use, implying the promotability of SRL within direct e-learning environments.

However, the studies presented agree that SRL can be fostered via e-learning but largely neglect pre-service teachers as a target group despite their important role as SRL multiplicators. Only a few SRL trainings focus on this special target group.

Alkhasawnh and Alqahtani (2019) conducted a study in which they provided direct SRL training to N = 70 education students from Saudi Arabia. They introduced an e-learning course with SRL strategies for the experimental group and without SRL strategies for the control group. The results showed that the experimental group, which received the SRL training, demonstrated increased self-regulated learning and better performance in the course compared to the control group. Dörrenbächer-Ulrich et al. (2019) utilized e-learning training to enhance SRL among N = 57 pre-service teachers, resulting in increased SRL traits, particularly in the motivational subscale, and improved SRL knowledge in the experimental condition. In a study conducted by Zeeb et al. (2024), the researchers worked with N = 119 pre-service teachers to explore the impact of digital learning diaries on the development of declarative and self-reported knowledge about learning strategies. Throughout the semester, the participants maintained a total of seven digital learning diaries, during which they received either peer feedback, assessment support, or both. The results indicate that declarative and self-reported SRL knowledge experienced a substantial increase. Furthermore, it was found that participants' engagement in journal writing and the exchange of peer feedback contributed to a deeper understanding of effective learning strategies. However, there was no significant overall improvement in the application of learning strategies during the semester, except when accompanied by high-quality feedback. This suggests that learners' application of learning strategies relies on the quality of the feedback they receive.

2.4.4 Fostering Self-Regulated Learning with Digital Games in Higher Education

There are still few educational games that support SRL, and research on this topic is still in its early stages. Dever et al. (2023) looked into promoting SRL with Crystal Island for N = 94 undergraduate students. Through the use of multimodal data (such as log files), which were assessed as objective markers of SRL, they attempted to infer SRL tactics employed by the learners. Two groups of participants were assigned, one of which was given scaffolding prompts to use during the game, and the other of which did not. The findings demonstrate that compared to those who did not receive scaffolding, game participants who received scaffolding prompts used SRL strategies more frequently.

Persico et al. (2023) developed a hybrid board game for in-service teachers called *SRL-4Ts-Game* to encourage teachers to think about improving pupils' SRL abilities. The research was a case study involving fifteen European in-service teachers. A pre- and posttest questionnaire was used to gauge the participants' perceived competence in SRL, knowledge of SRL, and opinions about the significance of promoting SRL. Teachers' perceptions of their SRL proficiency improved as a result of the game, and perceived competence and SRL knowledge significantly increased.

Because few games and studies exist on the subject of SRL, the presented results indicate that more games need to be developed and investigated to support SRL. Furthermore, to the author’s knowledge, no digital educational game focuses on promoting SRL in pre-service teachers, revealing a gap in research that the current thesis tries to close.

2.4.5 Fostering Self-Regulated Learning with Digital Games in School

As shown in Chapter 2.4.3, pre-service teachers’ self-regulated learning skills and knowledge can be trained with e-learning to prepare them for promoting their students’ SRL skills in the classroom. For students in higher education, digital games positively affect SRL and seem promising for teacher education. However, digital games cannot only be beneficial for pre-service teachers but can also be used by teachers to improve SRL skills and knowledge acquisition for students in the classroom.

In general, few randomized controlled studies have been conducted on the effectiveness of digital game-based learning interventions in the school context, and further investigation is still needed. Therefore, even fewer studies examine the effectiveness of digital games in promoting pupils’ SRL with high-quality studies. *Mission with Monty* is a game designed to encourage metacognitive monitoring skills and was examined by Sperling et al. (2022) with $N = 224$ fifth graders. The game group's metacognitive monitoring skills improved compared to the control group. The popular microbiology game *Crystal Island* is frequently utilized to investigate the advancement of SRL in secondary education (Rowe et al., 2011). Due to its requirement of strategic planning, execution, and control over the activities that students participate in, this game promotes SRL. Students must also keep a record of the evidence they have gathered in order to monitor their gameplay.

The effectiveness of digital games must first be ensured in order to develop an effective game that can successfully promote SRL. Taking into account the rapid technological progress, an analysis of the general effectiveness of current games in the school context must first be carried out. Based on the results, initial assumptions can then be made about the effectiveness of the games for the specific construct of SRL to plan and design an educational game for pupils in the next step.

3 Research Aims

Based on the presented background, the main research aim of the current thesis is to examine self-regulated learning in digital learning environments, focusing on its double role as a prerequisite for digital learning as well as being an improvable competence. In order to achieve the aim of the thesis, a meta-analysis and three empirical studies were carried out. As a first step, SRL's role in technology acceptance as a prerequisite for digital learning was examined (Study I). Study II analyzed pre-service teachers' SRL profiles in two different digital learning environments to investigate how to improve SRL in pre-service teachers and students. In a subsequent step, a digital educational game was created to enhance self-regulated learning for pre-service teachers (Study III). A meta-analysis (Study IV) was carried out to investigate the effectiveness of digital educational games on pupils in the school context. The studies conducted will be explained in more detail in the following chapters.

3.1 Study I

As mentioned in Chapter 2.2, digital learning environments can support learning processes and impart knowledge to learners. E-learning has become an integral part of university teaching, particularly during and after the COVID-19 pandemic. To effectively offer digital learning environments, students must willingly accept and use the technology provided. Even the best e-learning platforms at universities are pointless if students refuse to use them. The acceptance of e-learning environments was examined based on the TAM (Davis, 1989) in Study I and extended with SRL as an important factor that influences technology acceptance. SRL is essential for effective learning in digital environments. In e-learning, learners have a high degree of autonomy and control over their learning process. They must schedule, choose when, and how to interact with the instructional materials that are being presented, maintain motivation, monitor, adapt, and reflect on their learning progress (Broadbent & Poon, 2015). A successful learning process in an e-learning environment results in positive feelings and beliefs regarding this technology. Therefore, SRL has been considered in the TAM (Schlag & Imhof, 2017) before, but not as an external factor that impacts technology acceptance directly. The aim of Study I is to integrate SRL as an important prerequisite and, therefore, an external factor for successful e-learning in the TAM. Assessing the component structure of SRL in TAM has not been studied yet, contributing to further evidence of its role in technology acceptance. In addition, Study I also contributes to the replication of the TAM regarding e-learning with German-speaking university students because most studies in terms of this topic are conducted in Asia (Granić & Marangunić, 2019; Scherer & Teo, 2019).

3.2 Study II

SRL is not only a prerequisite for learning in digital learning environments but also a promotable competence. As explained in Chapter 2.4.2, pre-service teachers could function as multiplicators of SRL for their pupils in the classroom (Karlen et al., 2023). Pre-service teachers can promote students' SRL in various ways, for example, by assigning challenging tasks (Dignath & Veenman, 2021). Pre-service teachers, in their capacity as role models, not only directly impart knowledge but also exhibit SRL strategies themselves (Peeters et al., 2014). In order to effectively teach their students and be a behavioral model for them (Peeters et al., 2014), pre-service teachers must first acquire sufficient skills for teaching SRL strategies themselves that can be nurtured by receiving high-quality education and acquiring self-regulated learning strategies early on. Digital learning environments are an ideal platform to provide pre-service teachers with self-regulated learning strategies in an adaptable manner and create ideal learning conditions (Ng, 2015). When designing digital learning environments, it is important to consider students' individual needs. A person-centered approach can provide a basis for future learning environments based on individual learning profiles. However, there is still a lack of knowledge about individual differences in SRL among learners, and previous studies analyzing SRL profiles of students have provided varying numbers of profiles. Additionally, pre-service teachers as a special target group and the effects of different learning environments (e.g., synchronous and asynchronous learning) have been neglected, highlighting the need for further investigation. Therefore, Study II aims to investigate the individual characteristics of pre-service teachers in two different learning environments to promote SRL. The objective is pursued through three research questions.

Research question one investigates whether there are different SRL profiles for pre-service teachers and determines their number. Research question two investigates whether SRL training has different effects on persons with different SRL profiles. Finally, the third research question examines whether different types of learning environments (synchronous, asynchronous) have different training effects depending on the SRL profiles. By investigating the research questions posed, the study contributes to research into the differential effects of learning in digital learning environments on pre-service teachers and promotes the derivation of recommendations for the development of learning environments that offer adaptive learning opportunities tailored to users.

3.3 Study III

As appeared in Chapter 2.1.3, studies uncovered that pre-service teachers regularly have divided or disorganized information on SRL procedures and strategies (Lawson et al., 2019; Ohst et al., 2015), causing incapable instructing of SRL methodologies within the classroom. It is vital to prepare pre-service teachers with SRL information and strategy knowledge to assist their pupils' development of SRL skills. Since pure e-learning environments require a high degree of discipline to complete them on time (Wong, 2007), Study III presents a potentially more motivating approach to promoting SRL among pre-service teachers by developing a digital educational game (Chang et al., 2017). The educational game "*Regulatia*" aims to foster SRL knowledge and skills by integrating play with instructional materials. During the game, pre-service teachers acquire SRL strategies and discover how to teach them to their future pupils. Hence, the game has the potential to make significant contributions to pre-service teacher training. To ensure *Regulatia* fits user needs, Study III evaluates the first functional prototype's usability and user experience, which can affect the game's success (Boulay et al., 2011; Pinelle et al., 2008). Three research questions are examined: First, we examine whether *Regulatia* is perceived as user-friendly. Second, we assess learners' perception of the different game elements, and third, we gather the game's strengths and weaknesses to improve the prototype further.

3.4 Study IV

To enable children to learn in a self-regulated way, SRL should be encouraged as early as possible. As described in Chapter 2.4, SRL can be supported in different ways, for example, directly and indirectly by the teacher. Digital games provide an innovative way to educate students in the classroom, as well-designed games can adapt to their individual needs (Plass & Pawar, 2020). Additionally, digital games provide a safe and supportive learning environment where students can make mistakes and learn from them. This “graceful failure” (Plass et al., 2015, p. 261) leads to mastery experiences, increasing pupils’ motivation and self-efficacy. Digital games facilitate a learner-centered approach, empowering students to actively create their own learning experiences within the game. According to Admiraal et al. (2011), pupils are a group that is often “bored and disengaged” (p. 1185), which is why DGBL interventions could promote their motivation. DGBL has been shown in prior meta-analyses to have beneficial effects on learning at all educational levels, from elementary school to university (Clark et al., 2016; Lamb et al., 2018; Wouters et al., 2013). However, the research in these studies was limited to work done until 2015. Technological development has advanced rapidly in the last five years, opening new possibilities for DGBL interventions. Games are easier to create and more affordable for teachers and researchers to use. The quantity of digital devices in schools has increased as a result of the ongoing digital transformation. These digital devices have improved graphics and memory capacity, which has made it easier to implement DGBL interventions in schools in recent years. Moreover, more intricate textures and game mechanics can be used in game development. Because of this, comparing DGBL interventions from ten years ago to those from the present is challenging. Furthermore, generalizing the results to particular subgroups is not possible because prior meta-analyses looked at a broad variety of target groups. Because students' motivational needs predispose them to benefit from DGBL interventions, Study IV looks at studies that focus on the pure school context and span a shorter, more recent period (2015–2020). In contrast to conventional learning techniques, the goal is to ascertain how well DGBL interventions, which are based on the *Integrated Design Framework for Playful Learning* (Plass et al., 2015), affect the SRL components measured through cognitive, metacognitive, and affective-motivational learning outcomes. Since metacognitive outcomes have never been studied before, this analysis expands on earlier meta-analyses. In addition, Study IV investigated not only the main effects of DGBL on various learning outcomes but also the effects of individual factors, learning environment factors, and confounding factors in order to derive recommendations for scientific and educational practice regarding the creation and use of digital games.

4 Overview of the Published Studies

4.1 Study I

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2024). Students' Acceptance of E-learning: Extending the Technology Acceptance Model with Self-regulated Learning and Affinity for Technology. *Discover Education*, *3*(114). https://doi.org/10.1007/s44217-024-00195-7.

Abstract

The present study examines university students' acceptance of e-learning according to the Technology Acceptance Model (TAM). We also investigate the influence of external factors, including self-efficacy with digital media, self-regulated learning, prior experience, and affinity for technology, to extend the model with valid individual factors. Structural equation modeling with maximum-likelihood estimation served to evaluate the proposed research model, which included online questionnaire data from N = 225 undergraduates studying various subjects in 53 universities. The results indicate that the TAM is replicable regarding e-learning for German-speaking university students. Additionally, we found self-regulated learning and affinity for technology to be significantly positively related to the two main components of the TAM, perceived ease of use and perceived usefulness, implying their importance in technology acceptance. However, self-efficacy with digital media and prior experience showed no significant impact on university students' technology acceptance. We also found a significant positive relationship between attitudes toward e-learning and behavioral intention, showing that university students with positive attitudes are more willing to use it in the future. Therefore, higher education should consider students' individual prerequisites for e-learning and support students during the use of e-learning environments to promote the development of positive experiences and attitudes toward e-learning.

4.1.1 Theoretical Background and Hypotheses

As discussed in Chapter 2.2, digital learning environments have the potential to provide optimal learning conditions and enhance learners' future skills. The current study is based on Davis's (1989) TAM, which predicts users' acceptance of technology and focuses on two main components that influence attitude, namely, perceived ease of use (PEU) and perceived usefulness (PU). According to the model, users are more likely to adopt a positive attitude toward a particular technology if they believe it to be practical and advantageous for their own performance (Zheng & Li, 2020). Additionally, adopting a positive mindset regarding the technology heightens users' behavioral intention to utilize it (Drueke et al., 2021).

Despite the well-established examination of TAM, there are still research gaps. The current study's goal is to incorporate two new factors—SRL and affinity for technology—into the TAM, along with other important factors necessary for effective e-learning. Furthermore, the study examines two inconsistencies in the model: self-efficacy and prior experience. While the learning variables that have been discussed can help learners succeed in online learning environments, even the best preconditions are meaningless if students are unwilling to use the platforms. Pan (2020) reports that university students who have a low acceptance of technology use fewer digital devices than those who have a high acceptance of technology. To improve the model's capacity for explanation, the TAM was expanded over time to include external variables, e.g., prior experience (Ros et al., 2014). SRL plays a key role in the effectiveness of online learning. Due to the high degree of autonomy afforded by e-learning environments, learners must schedule their interactions with the material, maintain motivation, and evaluate their progress (Broadbent & Poon, 2015). The influence of SRL as an external factor remains unclear, as previous studies have only examined SRL as a result of technology acceptance in the TAM (Schlag & Imhof, 2017). Since SRL is a crucial prerequisite for digital learning (Kizilcec et al., 2017), the current study examines it as an external factor in the TAM. SRL's component structure has not yet been evaluated in TAM, adding to the body of research showing how SRL influences technology acceptance.

Additionally, when learning through e-learning, a person's affinity for technology also matters. According to Karrer et al. (2009), affinity for technology is a personality trait that is defined by a favorable attitude toward technology, excitement for it, and a concomitant level of trust in electronic gadgets. We included the affinity for technology as an external factor in TAM exploratorily because positive attitudes toward it may increase a person's likelihood of accepting it. Another important factor to consider in TAM is self-efficacy. It represents “people’s beliefs about their capabilities to exercise control over events that affect their lives” (Bandura, 1989, p. 1175).

Given its significance as a motivating component of SRL, self-efficacy has been incorporated into a number of theoretical models of SRL (Panadero, 2017). It affects, for instance, whether or not a learning activity is started (Zimmerman, 2000). Individuals with low self-efficacy may experience discouragement and delay beginning their task, whereas learners who are confident they can solve an exercise will probably work toward a solution. According to

Bandura's (2006) theory, self-efficacy is context-dependent and, once established, context-stable. Self-efficacy with digital media is crucial when it comes to the particular context of e-learning. As a result, it symbolizes people's confidence in their ability to use digital media (such as e-learning environments) and their belief that they can get past technical challenges. Previous research has shown that computer self-efficacy has been frequently implemented in TAM but not self-efficacy with digital media.

One of the most studied external factors in TAM, along with self-efficacy, is prior experience; however, results for these constructs regarding university students are not consistent. Abdullah and Ward (2016) examined the most often utilized TAM factors for various target groups in their systematic review. Overall, they discovered positive findings about the impact of both self-efficacy and prior experience on technology acceptance; however, when concentrating on the student population, they discovered that 33% of the studies on self-efficacy and 78% of the studies on prior experience failed to find a significant impact on technology acceptance. This necessitates a deeper examination of the two student population factors. As a result, the current study aims to analyze the impact of factors for successful e-learning as external factors in the TAM, including prior experience with e-learning, self-efficacy with digital media, affinity for technology, and SRL. We deduced a hypotheses-based structural equation model (SEM), assuming a positive relation of the TAM-variables PEU and PU in hypothesis 1 (H 1) and their positive impact on attitude towards e-learning (H 2, H 3). According to the model, we hypothesized that a positive attitude toward e-learning passively impacts the behavioral intention to use e-learning (H 4). For SRL, we assumed a positive relation with PEU (H 5) and PU (H 6). For self-efficacy with digital media, we hypothesized a positive impact on PEU (H 7), PU (H 8), behavioral intention (H 9), and SRL (H 10). We also suggested a positive relation of prior experience with PEU and PU (H 11 and H 12), and the same assumptions were applied to the affinity for technology (H 13 and H 14).

4.1.2 Procedure and Methods

The sample comprised N = 225 undergraduates studying different subjects (20% male, 78% female, 0.8% diverse, 1.2% no information) from 53 German-speaking universities. Participants were M = 23.18 years on average (SD = 4.67) and in their fourth semester of studies (M = 4.23, SD = 2.75).

The data were assessed via an online survey implemented on the *Tivian* platform. The participants took approximately 15 minutes to complete the questionnaire. The questionnaire included eight scales to measure the relevant constructs. Perceived usefulness was assessed with six items (Masrek et al., 2010) and perceived ease of use was examined by using the System Usability Scale (Brooke, 1996) consisting of ten items. Attitude toward e-learning was measured with 12 items (Mishra & Panda, 2007), and the behavioral intention to use e-learning was examined with three items (Venkatesh & Bala, 2008). Self-efficacy with digital media was measured with a combined scale comprising five items by Lin et al. (2016) and two items by Hung (2016). Affinity for technology was assessed with 19 items (Karrer et al., 2009). These scales used a five-point Likert scale (1 = "*totally disagree*", 5 = "*totally agree*"). SRL was assessed with 55 items (Dörrenbächer & Perels, 2016) that could be assigned to three different subscales, representing the three components of SRL (cognition, metacognition, and motivation). Prior experience with e-learning was determined with a self-designed item. For these scales, a four-point Likert scale was used (1 = *"totally disagree"*, 4 = *"totally agree"*). All scales reached an acceptable to excellent level of reliability for the sample (Cronbach's α = .66 - .96).

Descriptive and correlational analyses were conducted using SPSS. To examine our hypotheses, we performed SEM in R. Due to the small sample size and violation of the normal distribution assumption, item parceling was applied to compensate for non-normality and to reduce the required sample size. Three parcels per factor were created using the single-factor method, ensuring equal factor loadings (Kenny, 1979) for all constructs except for SRL. Due to its multidimensionality, the three components of SRL (cognition, metacognition, and motivation) were represented by building the three facet-representative parcels. To confirm the reliability and validity of the examined constructs, a measurement model was tested. In the next step, we tested the proposed structural model by examining the causal relationships between the constructs. A significance level of α = .05 was postulated for all statistical tests.

4.1.3 Results

To evaluate our proposed research model, we followed a two-step procedure. Firstly, the measurement model was examined to determine its fit, reliability, and validity regarding convergent and discriminant validity. Secondly, the structural model was analyzed using SEM and maximum-likelihood estimation.

To examine the fit of the measurement model, the χ^2-test, along with indices such as the comparative fit index (CFI), the standardized root mean square residual (SRMR), and the root mean square error of approximation (RMSEA) were used. All indices met the cut-off criteria according to Hu and Bentler (1999), indicating the model's robustness (CFI = .96, SRMR = .04, RMSEA = .05). However, the χ^2-test resulted in a significant deviation from the given data ($\chi^2(218) = 338.40$, $p < .001$) for the model. If all the indicators used are considered together, the overall impression is of a robust model.

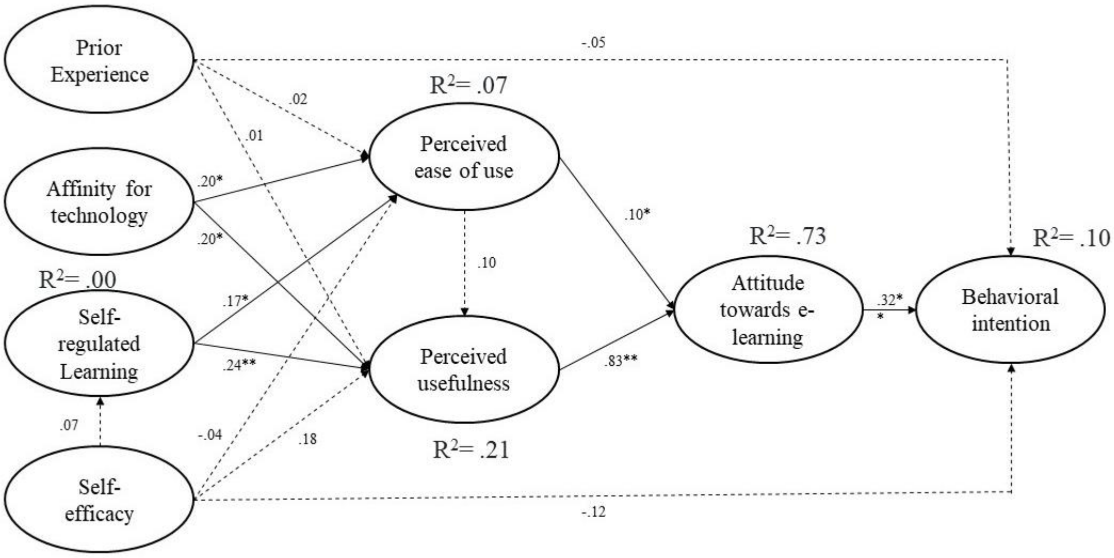
To achieve a reliable measurement model, we followed Fornell and Larcker's (1981) specifications. After removing all items with factor loadings lower than .50, the factor loadings of the selected items were between .50 and .97, indicating a reliable measure. The convergent validity was confirmed by the high internal consistency (Cronbach's α = .80-.96) and the high average validity extracted (AVE = .57-.90). Because all correlations between the latent variables are smaller than .80 and the squared correlations are smaller than the AVE, discriminant validity can be assumed according to (Kline, 2016).

The evaluation of the structural model revealed a good model fit for the indicating parameters (CFI = .95, RMSEA = .06, SRMR = .07), with the exception of the χ^2-test ($\chi^2(213) = 365.06$, $p < .001$). After verifying the fit of the structural model, we investigated the structural paths, t-values, and the variance explained (R^2). Seven of the hypothesized paths between the latent constructs were significant and in the proposed direction. There was no significant interrelationship between PEU and PU (H1 rejected), but both constructs influenced the attitude towards e-learning positively (H2 and H3 accepted), which, as hypothesized, had a positive influence on behavioral intention (H4 accepted). For SRL, a positive relationship with PEU and PU could be confirmed (H5 and H6 accepted). However, the results showed no significant positive influence of self-efficacy with media on PEU, PU, behavioral intention, or SRL (H7 to H10 rejected). Prior experience did not affect PEU, PU, or behavioral intention (H11 to H13 rejected). Affinity for technology was found to be a positive predictor of PEU and PU (H14-H15 accepted).

The model's visualization is presented in Figure 2. Findings show that both the affinity for technology and SRL together explain 7% of the variance in PEU and 21% of the variance in PU. The combined effect of PEU and PU was found to explain 73% of the variance, while the attitude explains 10% of the variance in behavioral intention.

Figure 2

Resulting Model With Model Estimates



Note. Significant paths are illustrated with solid lines.

4.1.4 Discussion

Study I examined students' technology acceptance in e-learning environments based on the TAM (Davis, 1989). To enhance the traditional TAM, we also explored additional external factors, such as self-efficacy with digital media, SRL, prior e-learning experience, and affinity for technology.

The study revealed that university students' attitudes toward e-learning are significantly influenced by the perceived usefulness (β = .10) and perceived ease of use (β = .83) of the e-learning environment. The findings demonstrated that PU had a greater influence on attitudes than PEU. University students who found e-learning platforms easy to use and navigate had more positive attitudes than those who found the platforms difficult and not user-friendly. As a result, we could apply and reproduce earlier research on e-learning (e.g., Cheung & Vogel, 2013; Chibisa et al., 2022; Ratna & Mehra, 2015). Furthermore, a positive relation was observed between the behavioral intention to use e-learning in the future and attitudes toward it (β = .32), indicating that highly positive attitudes toward e-learning increase the likelihood of future use by university students. The results of earlier studies on e-learning (Hanif et al., 2018; Ranellucci et al., 2020) are consistent with these findings.

Despite our initial hypothesis, we discovered that there is no significant relationship between PEU and PU, which aligns with previous studies (e.g., Koutromanos et al., 2015). However, Wong (2015) and Teo and Milutinovic (2015) found evidence for a relationship between the two constructs. Our sample had high e-learning experience (*M* = 3.45), possibly affecting the relationship. Given the prevalence of e-learning due to the COVID-19 pandemic, students may have lower difficulty using e-learning environments but higher expectations for usefulness, diminishing the influence of PEU on PU. In summary, while PEU and PU impact attitudes and behavioral intention toward e-learning, there is no direct path from PEU to PU.

We moreover inquired about the impact of external factors such as self-efficacy with digital media, SRL, prior experiences with e-learning, and affinity for technology on university students' acceptance of e-learning. Although computer self-efficacy had a positive impact in the TAM context previously, the current research did not find any evidence to support digital media self-efficacy as an external factor in the TAM. For e-learning, self-efficacy with digital media might be too global due to its context specificity, which is why our study found no positive correlation with PEU and PU. Due to the high level of self-efficacy our sample exhibited with digital media (*M* = 3.98), there was a ceiling effect and variance restriction. It appears that students are convinced they can use the system regardless of the amount of effort required, so it does not matter if e-learning is viewed as helpful or user-friendly anymore. Due to a strong preference for in-person events during and after the COVID-19 pandemic, self-efficacy did not appear to have an impact on the behavioral intention to use e-learning (Mali & Lim, 2021).

In addition, there was no discernible predictive relationship between SRL and self-efficacy, contrary to what the existing literature (e.g., Sadi & Uyar, 2013; Zhu et al., 2020) assumes. The degree to which this study's self-efficacy and SRL items match may cause some concern. Digital media is specifically addressed in the self-efficacy assessment items of the SRL questionnaire, which pertains to learning in general. The absence of a possible effect might have resulted from this deviation. Moreover, self-efficacy had no effect on behavioral intention, which is at odds with previous research. Many studies have found that behavioral intention toward e-learning positively correlates with self-efficacy (Cheung & Vogel, 2013; Joo et al., 2018). The wording of the self-efficacy items may explain this if it is not explicit enough. SRL significantly affects both PU (β =.24) and PEU (β =.17). In online learning environments, PEU and PU are typically higher among university students with stronger self-regulation abilities. This is because SRL covers competencies like goal-setting and monitoring that are necessary for learning in digital environments (Azevedo et al., 2010).

Better learning outcomes result from people with SRL finding e-learning more convenient and helpful. Conversely, previous experience did not prove to be a predictor of behavioral intention, PEU, or PU. According to the research, e-learning experience is not always a guarantee that one will find it helpful or easy to use. The students in the sample had a lot of experience with e-learning. Owing to the pandemic's digital teaching, students now regularly study in e-learning environments. These encounters, however, were not always voluntary, so they cannot be used as a predictor of PU, PEU, or behavioral intention. These findings conclude that prior adoption of an appropriate learning strategy precedes an increase in PEU or PU, but prior use of e-learning does not guarantee such an outcome.

The affinity toward technology was a recently added external component to the model. The findings support the hypothesis that students who are receptive to new ideas and open to utilizing them find e-learning environments to be easy to use and beneficial. On the other hand, a bad impression will arise from university students who detest technology and avoid using e-learning.

The study replicated the TAM for e-learning among German-speaking university students and identified additional external factors, such as self-regulated learning and affinity for technology. However, the study has limitations, including a small sample size and non-normal data distribution. Item parceling was used to compensate for this, but it comes with controversy due to the potential loss of information (Little et al., 2013). Additionally, several items representing SRL's motivational component were omitted because of low factor loadings, potentially missing important motivational aspects.

The assessed data's reliance on self-reporting raises methodological concerns about potential bias and intentional deception to appear favorable. To enhance the study's robustness, a mixed-methods approach, such as using both self-report questionnaires and interviewing close contacts, could have been employed to assess attitudes toward e-learning. Additionally, the study's general assessment of SRL without a specific focus on e-learning may have affected its alignment with other e-learning-specific scales. The broad definition of e-learning Clark and Mayer (2016) used in the study may have led to varied participant interpretations and possible confounding of results due to the heterogeneous nature of e-learning components. Lastly, the study did not assess actual e-learning use, relying solely on participants' behavioral intentions without examining their actual behavior. For the first time, Study I employed the component structure of SRL as parcels to serve as an input for the TAM rather than an output. The findings offer a first understanding regarding the consideration of SRL as a determinant for technology adoption in the future and strengthen the importance of SRL as a prerequisite for online learning. According to Study I, tech-inclined students with strong SRL abilities will be more receptive to online learning. Thus, it is critical to foster SRL skills as early as possible by introducing explicit strategy use in university courses. By encouraging a positive attitude toward e-learning and technology through mastery experiences, technology-related fears can be reduced by engaging with digital media and methodical use of e-learning.

4.2 Study II

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2024). Fostering Self-regulated Learning in Pre-service Teachers Using Synchronous or Asynchronous Digital Learning Environments: A Latent Profile Analysis of Pre-Service Teachers' Individual Differences. *Frontiers in Education*, 9:1445182. https://doi.org/10.3389/feduc.2024.1445182

Abstract

Self-regulated learning is positively associated with improved learning achievements during all educational phases. Despite playing an important role in conveying SRL strategies to their students, pre-service often lack knowledge about SRL and imparting it. Therefore, addressing SRL and teaching SRL strategies to students seems relevant to pre-service teacher training. The present study aims to analyze pre-service teachers' SRL profiles in asynchronous and synchronous digital learning environments. and compares their influence on training effectiveness. As part of a pre-post design, a total of N = 141 pre-service teachers participated in the study, and questionnaires on SRL strategy use and an SRL knowledge test were used. A latent profile analysis indicated a three-class solution (low, moderate, high SRL), revealing significant differences regarding SRL strategy use but not for SRL knowledge. These findings enable a person-centered approach to develop digital learning environments and provide insight into specific learner behavior.

4.2.1 Theoretical Background and Research Questions

As discussed in Chapter 2.3, research indicates that students who possess the ability to self-regulate their learning are more likely to succeed in digital learning environments and to finish tasks without interruption than students who lack these skills (Alhazbi & Hasan, 2021). Since SRL has been shown to improve learning across all subject areas (Dent & Koenka, 2016), it is important to promote SRL from an early age. Pre-service teachers have a special responsibility to support their students' SRL, but they also need to have the necessary skills to help students understand the concept.

For this reason, it is imperative that pre-service teachers are exposed to SRL as early as possible in order to equip them with the knowledge and abilities needed to instruct students in explicit learning strategies and act as models for their pupils in the classroom (Peeters et al., 2014).

For pre-service teachers to receive SRL strategies in a flexible and safe manner, digital learning environments are a suitable setting. Taking into account each student's unique learning needs is essential to creating digital learning environments that are effective (Wong, 2023). This requirement appears to be best served by a person-centered approach, as individual learning profiles can be examined and used as a foundation for developing future learning environments. For the number of pre-service teachers’ SRL profiles, research findings are still inconsistent, and only a few studies are focusing on this special target group. For pre-service teachers, two-profile solutions (Huang et al., 2021) and three-profile solutions (Heikkilä et al., 2012; Muwonge et al., 2020) were reported. However, there are also studies with university students revealing four-profile (Araka et al., 2020; Dörrenbächer & Perels, 2016; Schwam et al., 2020) or even five-profile solutions (Barnard-Brak et al., 2010) which might be transferable to pre-service teachers as a subgroup of university students. The results that are being presented show varying numbers of SRL profiles for pre-service teachers and university students, which makes determining the precise number of profiles challenging. It is possible to categorize SRL competencies by analyzing SRL profiles, which provide insight into learners' requirements. This presents the option of encouraging a deficiency in competencies for students with low SRL profiles or customizing learning settings for students with advanced SRL abilities.

Chapters 2.3 and 2.4 show that SRL is a prerequisite for learning in digital environments and, simultaneously, a competency that can be improved in digital learning environments.

The lack of in-person interactions in digital learning environments highlights how crucial communication is. It can be distinguished between synchronous and asynchronous communication. Synchronous communication is defined as the teacher-student exchange that takes place in real-time (Alhazbi & Hasan, 2021; Amiti, 2020; Shahabadi & Uplane, 2015). Online instruction and learner-oriented interaction are made more accessible by synchronous technologies, such as virtual meetings and live discussions (Giesbers et al., 2014; Watts, 2016). Asynchronous communication does not rely on time, so both the teacher and the students can participate at different times (Amiti, 2020). Learning materials are prepared by the teacher, and communication happens through asynchronous technologies like recorded lectures, forums, or messaging platforms (Alhazbi & Hasan, 2021; Reese, 2015). Whereas asynchronous communication increases student engagement with the content because learners have more time to interact with, process, and reflect on the learning material, synchronous learning is adequate for collaborative learning because synchronous tools offer a high level of media richness, facilitating a more profound learning process (Rockinson-Szapkiw & Wendt, 2015). Compared to synchronous learning, students can achieve higher levels of cognitive achievement when they are allowed to reflect on a problem and formulate their response instead of responding immediately. This enables them to participate in critical thinking and generate higher-quality responses (Ogbonna et al., 2019). To summarize, both synchronous and asynchronous learning environments can potentially promote SRL (Shahabadi & Uplane, 2015), but it is still unclear whether there are differences regarding the effectiveness of SRL training between both communication styles.

Therefore, the purpose of this study is to compare the efficacy of SRL training with respect to the acquisition of SRL strategies and knowledge, as well as to investigate the individual SRL characteristics of pre-service teachers in two digital learning environments: synchronous online seminars and asynchronous e-learning.

The need for more research is highlighted by the paucity of information regarding the individual differences among learners in SRL and the fact that studies examining students' SRL profiles offer varying numbers of profiles while ignoring the unique target group of pre-service teachers. Furthermore, more research is required to examine how individual preferences in synchronous and asynchronous learning environments affect SRL's promotability. Consequently, the current investigation looks into the following three research questions: (1) Are there different SRL profiles for pre-service teachers, and if so, how many? (2) How does SRL training affect pre-service teachers with different SRL profiles? (3) What are the differences between synchronous and asynchronous learning environments regarding the effectiveness of SRL training for the different SRL profiles?

4.2.2 Procedure and Methods

The sample included N = 145 pre-service teachers (72% female, 26% male, 0,7% diverse, 0,7% not specified) from a university in southwestern Germany who were, on average, M = 24.24 years old (SD = 4.50). The participating pre-service teachers were in their seventh semester of studies (SD = 2.09). The students were selected from preexisting compulsory courses in educational science. Each course (n = 11) was randomly assigned to one of the two training conditions (synchronous online seminar, asynchronous e-learning). Thus, n = 90 students participated in the asynchronous e-learning condition, and n = 51 students participated in the synchronous online seminar. An online survey was used to collect data before the intervention (pretest) and after the six-week training (posttest). The average duration to complete the questionnaire was 20 minutes.

To predict student's SRL profiles, the self-reported use of SRL strategies was examined with an SRL scale (Dörrenbächer & Perels, 2016) comprising 56 items and representing all three phases of Zimmerman's SRL model (2000). A four-point Likert scale (1 = "*totally disagree*", 4 = "*totally agree*") was used in the questionnaire. An overall score, as well as sub-scores for the different components of SRL (cognition, metacognition, motivation), were calculated, and acceptable to high-level reliability was indicated for the sample (Cronbach's α = .61 - .93).

To determine whether participants experienced training gains, declarative SRL knowledge was measured with a knowledge test (Dörrenbächer-Ulrich et al., 2019). A research assistant scored each answer using a standard sample solution, with a total of 28 possible points. During the six-week training intervention, the participants were divided into two learning environments, namely asynchronous e-learning and a synchronous online seminar. Zimmerman's (2000) SRL model provided the basis for the training content and material. In the synchronous online seminar, a trained instructor offered a weekly online seminar via MS Teams, whereas the participants in the asynchronous e-learning environment had six weeks to complete an e-learning course on Moodle on their own. The content in both conditions included six topics (see Table 1). The content was identical in both training conditions; the learning environments only differed in the communication style and the presence of an instructor.

Table 1

Topics and Their Classification into SRL Phases and Components

SRL Phase	Topic	Component
Forethought	Goal setting	Metacognitive
	Time management	Metacognitive
	Self-efficacy and self-motivation	Motivational
Performance	Stress and concentration	Motivational
	Learning strategies	Cognitive
Reflection	Self-reflection and causal attribution	Metacognitive / Motivational

A latent profile analysis (LPA) was conducted with *MPlus* to identify an ideal number of learning profiles based on the scores of the SRL component subscales. The fit of the competing models was determined by using the Bayesian Information Criterion (BIC), the Akaike Information Criterion (AIC), and the Lo-Mendell-Rubin Test (LMRT), together with entropy (E) as an indicator for classification accuracy (Marsh et al., 2009). The classifications were transferred to *SPSS*. To investigate how the SRL training affects pre-service teachers with different SRL profiles and whether the communication style influences learning regarding pre-service teachers' SRL profiles, analyses of variance (ANOVA) were performed to compare training gains for SRL strategy use and declarative SRL knowledge in the two different learning environments.

4.2.3 Results

Regarding research question one, the results revealed the best fit for a three-class solution for pre-service teachers' SRL profiles. The two-class solution could not fulfill the .80 threshold for the entropy, and it had the highest AIC value. The four-class solution resulted in a slight increase in BIC but a decrease in AIC, as compared to the three-class solution. Although both models had the same classification accuracy, the LMRT p-value was significant only for the three-class solution and not for the four-class solution. The three-class solution had lower BIC values than the five-class and six-class solutions, and the p-value was insignificant for both models. Table 2 shows the fit indices for all estimated models.

Table 2

Fit Indices for all Estimated Models

Classes	df	BIC	AIC	Entropy	LMRT (p-value)
2	10	340.05	310.78	.73	<.001
3	14	320.49	279.51	.84	<.001
4	18	326.41	273.72	.84	.108
5	22	338.76	274.36	.87	.368
6	26	351.80	275.70	.86	.816

Note. df = Degrees of freedom, BIC = Bayesian Information Criterion, AIC = Akaike Information Criterion, LMRT = Lo-Mendell-Rubin Test

Three profiles were identified based on participants' SRL components. Profile 1 represented the smallest group (5%) with low values on all SRL components (“low SRL”), Profile 2 (37%) had high values on all three components (“high SRL”), and Profile 3 (58%) showed moderate values in the motivational component and low values in the cognitive and metacognitive components (“moderate SRL”).

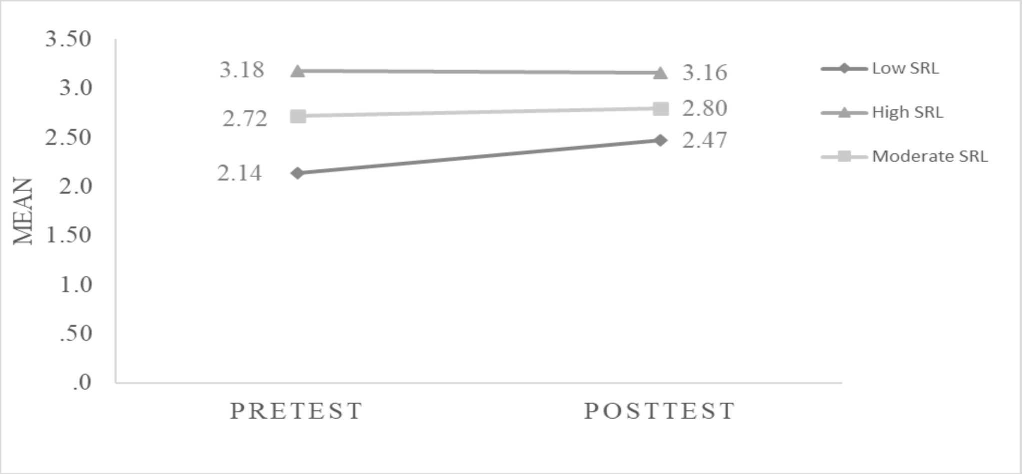
To verify the validity of the profiles, separate univariate ANOVAs were conducted, with each SRL component being the dependent variable and the profiles being the independent variable. As expected, due to the LPA, the results showed significant variations between all three profiles concerning all SRL components, with all Scheffé p-values being less than .001. There were no significant differences between the profiles in terms of declarative SRL knowledge before the intervention (F (2,135) = 2.26, p = .109, η^2 = .03).

Regarding the training effect on self-reported SRL strategy use and declarative SRL knowledge based on the SRL profiles and the communication style (research questions two and three), two ANOVAs were conducted with time (pretest/posttest) as within-subject factor and profiles and training conditions (synchronous/asynchronous) as between-subject factors. The dependent variables of SRL strategy use and declarative SRL knowledge were analyzed separately.

For SRL strategy use, the findings hint at significant differences regarding training gains between the profiles (F (2,112) = 5.35, p = .006, η^2 = .10). According to the Scheffé post-hoc comparisons, there were significant differences among all profiles (p < .001). The results neither indicated an interaction of time and condition (F (1,112) = .02, p = .896) nor an interaction of both factors with the profiles (F (2,112) = .13, p = .883). Figure 3 illustrates the difference in the average self-reported use of SRL strategies before and after the intervention.

Figure 3

SRL Strategy Use Means and Their Progression



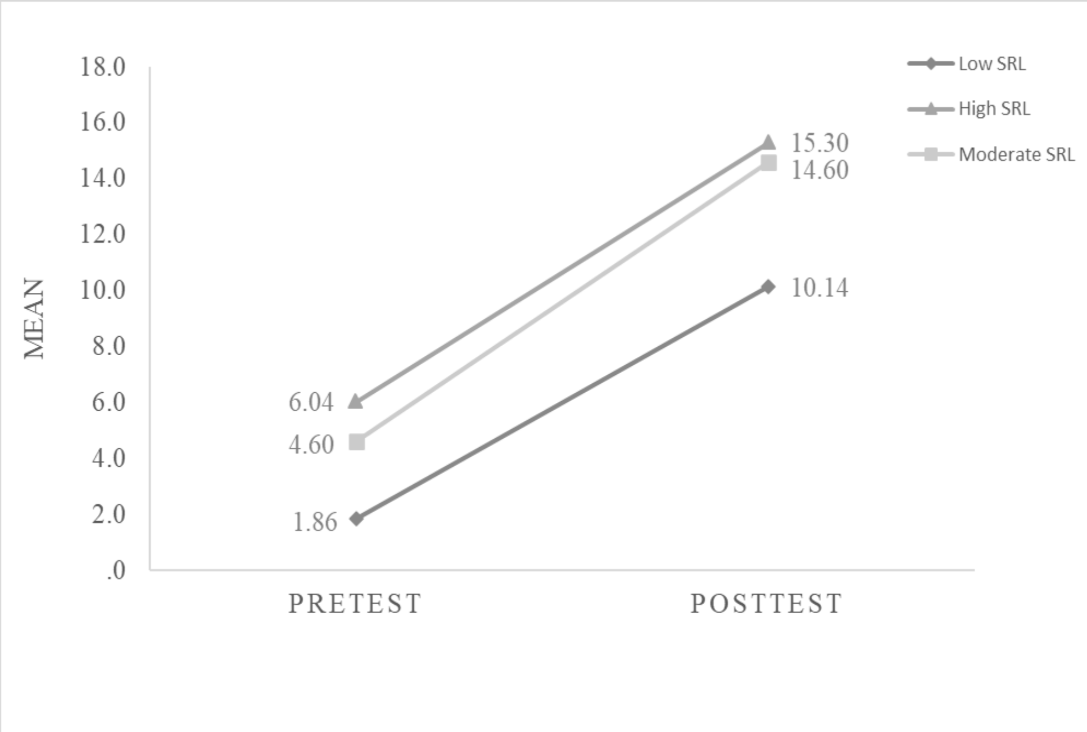
Note. The two groups (synchronous/asynchronous) are averaged in the figure.

Wilcoxon tests were used to analyze the training gains of different profiles with SRL strategy use as the dependent variable. The SRL strategy use increased in persons with the low (z = 2.03, p = .043) and the moderate profile (z = -3.09, p = .002) after training, but not for persons with the high profile (z = -.15, p = .882).

For declarative SRL knowledge, all participants showed a statistically significant increase in their declarative SRL knowledge (F (1,112) = 62.78, p <.001, η^2 = .36) which was not caused by the profiles due to the lacking time*profile interaction (F (2,112) = 0.14, p = .869, η^2 = .00). The mean change in declarative SRL knowledge is presented in Figure 4. The results indicate a dependence of the training gains on the communication style (F (1,112) = 4.46, p = .037, η^2 = .04) because the asynchronous e-learning condition reached higher scores in the declarative knowledge test than the synchronous seminar condition. However, this increase was independent of the profiles (F (2,112) = .15, p = .864, η^2 = .00).

Figure 4

SRL Knowledge Means and Their Progression After the Intervention



Note. The two groups (synchronous/asynchronous) are averaged in the figure.

4.2.4 Discussion

In Study II, we aimed to explore how the individual SRL characteristics of pre-service teachers impact the effectiveness of two digital learning environments using a person-oriented approach. Additionally, we compared synchronous and asynchronous communication styles in terms of self-reported SRL strategy use and SRL knowledge.

The results indicate three different SRL profiles of pre-service teachers: a low, a moderate, and a high SRL profile. This is consistent with research that also found a three-class solution (Ainscough et al., 2019; Chen et al., 2023; Esnaashari et al., 2023; Muwonge et al., 2020).

The smallest group in our sample was the low-profile group. The majority of people were classified as having a moderate profile. The motivational component is especially stressed for both the low-profile and the moderate-profile groups; however, the profiles are most different in terms of the cognitive and metacognitive components. This is consistent with research by Hirt et al. (2021), who found that people with high SRL use more cognitive and metacognitive strategies, while people with low SRL use fewer cognitive strategies. More than 60% of the participants were classified as having a low or moderate SRL profile, indicating room for improvement. These findings support the need for pre-service teachers to receive SRL training.

In terms of SRL strategy use, individuals in the low profile appeared to benefit most from the training, as evidenced by their highest gains in this area, which approximated the moderate profile in terms of compensation effect. This is consistent with the findings by Esnaashari et al. (2023), who ran a 12-week blended learning course and found that university students with low SRL profiles used SRL strategies at similar levels to those with average SRL profiles after the course. Unlike the current study, Dörrenbächer and Perels (2016) discovered that students with a moderate SRL profile also showed a compensatory effect, benefiting more from an eight-week training intervention than students with a low or high profile.

In terms of declarative SRL knowledge, all profiles showed a significant increase in declarative SRL knowledge; however, the low profile scored much lower than the moderate and high-profile groups. In the declarative knowledge test, individuals in the low-profile group scored less than half of the possible points (35%), while those in the moderate- and high-profile groups only achieved 50% correct answers despite a significant increase in knowledge across all groups. While this validates the efficacy of the instruction, it also indicates that the participants were unable to fully utilize the training material to improve their declarative SRL knowledge.

A potential limitation may be that the six-week training period was insufficient, given the volume of information imparted to the participants. This is consistent with Chen's (2022) meta-analysis, which supports the notion that students require sufficient time to develop self-regulation skills, particularly when the interventions are carried out in real-world settings. Furthermore, the training's efficacy might have been impacted by the participants' motivation and enthusiasm for the subject. Because the study was conducted in various required elective courses, some participants may not have been as motivated or interested, which would have limited their ability to get the most out of their training. It is interesting to note that there appears to be a disconnect between declarative SRL knowledge and self-reported SRL strategy use, as indicated by the lack of correlation between the two constructs (Dörrenbächer-Ulrich et al., 2021). High-level SRL knowledge in our sample does not necessarily translate into high-level SRL usage. Those with high levels of SRL knowledge may also employ a variety of SRL strategies, but they may not be aware of doing so and so be unable to report it on a questionnaire.

We found that there were no significant differences in SRL strategy use between asynchronous and synchronous learning environments after training. Both groups increased their strategy use, suggesting that both communication types effectively support SRL strategy training. Participants in the asynchronous e-learning condition showed higher training gains in declarative SRL knowledge compared to the seminar condition, possibly due to more time for reflection and deeper processing of information (Lucas et al., 2014). Overall, the results suggest that asynchronous environments may be more suitable for teaching SRL knowledge due to their suitability for comprehensive and complex topics. The e-learning environment is one limiting factor. There were students who finished the course ahead of schedule and others who put it off until the last minute. The assessment did not check for adequate content; it just documented course completion, not time spent. The methodology presents certain challenges, such as a limited sample size, a small profile size for Profile 1, and low reliability for the SRL's cognitive subscale. Additionally, the current study makes use of quasi-randomized participant data from various courses taught by various instructors at the same university. Multi-level model analysis may have been used to examine the potential impact of this nested data structure on the results.

The results of Study II highlight the significance of a person-centered approach when it comes to digital learning environments in order to meet the unique needs of pre-service teachers. The findings show that, generally speaking, SRL training for pre-service teachers with varying SRL profiles is beneficial, particularly for declarative SRL knowledge. However, additional modification is required to better serve students who already possess advanced SRL abilities.

4.3 Study III

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2024). The Evaluation of an Educational Game to Promote Pre-Service Teachers' Self-Regulated Learning. *Entertainment Computing, 52*, 100836. https://doi.org/10.1016/j.entcom.2024.100836

Abstract

The present study describes the evaluation of *Regulatia*, an immersive web-based educational game for pre-service teachers to promote self-regulated learning (SRL). Based on Zimmerman's model of SRL, learners immerse themselves in the underwater kingdom *Regulatia* and must find a way back home. *Regulatia* fosters the use of SRL-specific strategies and combines game elements with learning content. In this paper, the goal is to evaluate the first functional prototype of the game, examining its usability as well as users' game experience to create a basis for an effective game in the future. The findings based on a sample of *N* = 31 pre-service teachers from a Southwestern German university indicate great usability and a good feedback system, high perceived knowledge improvement, and pleasant visual aesthetics. Potential for optimization was revealed for the scope and the level progression of the game.

4.3.1 Theoretical Background and Research Questions

As shown in Chapter 2.4.4, the foundation for students' SRL development in the classroom and their lifelong learning can be laid by using DGBL to support SRL in higher education and among in-service teachers. Nonetheless, prior research on promoting SRL through DGBL has not considered pre-service teachers. To avoid having to learn SRL strategies later in life and better prepare pre-service teachers for their careers as classroom teachers, it is crucial to give pre-service teachers strategies for teaching them during their studies. Because of this, the goal of the educational game *Regulatia* is to enhance the knowledge and abilities of pre-service teachers in SRL by fusing playful learning with theoretical learning. Pre-service teachers learn SRL strategies through gameplay and gain experience in imparting them to their future students. As a result, *Regulatia,* the first SRL game specifically designed with pre-service teachers in mind, has the potential to impact teacher training significantly. Study III looks at three research questions to make sure the game meets the needs of its users: (1) Is the game perceived as user-friendly, represented through the game's usability? (2) How do learners perceive *Regulatia*, examined through the assessment of the participants' user experience of the different game elements playability, narrative, play engrossment, enjoyment, visual aesthetics, feedback, challenge, and knowledge improvement?, and (3) What are the strengths and weaknesses of the current prototype, assessed through open-ended questions regarding what the participants liked and disliked about the game?

4.3.2 Procedure and Methods

The study comprised N = 31 pre-service teachers from a German university (74,2 % female, 25,8 % male) with an average age of 23 years (M = 22.58, SD = 3.15). The sixth semester (SD = 3.93) was the average for the participating students. The study was conducted in two parts.

During the first part, participants were instructed to play the game *Regulatia* with an emphasis on playing deliberately. According to the instructions, they could explore and use every feature in the game. Participants were required to play until they reached level two and for at least 30 minutes.

Zimmerman's (2000) SRL model served as the foundation for the game's theoretical content and exercises, which addressed each of the three stages of self-regulated learning. *Regulatia* is a learning game that creates an immersive experience through the use of an underwater metaphor-based narrative. When players first launch the game, they find themselves in *Regulatia*'s endless ocean after stumbling into an enigmatic vortex during their beach vacation. The learners must free the imprisoned queen of *Regulatia* from the *Coral Tower* to return home. *Regulatia*'s self-regulation keepers possess the four pearls of self-regulation, which the learners must obtain to save the queen. Traveling through *Regulatia* and completing the self-regulation keepers' exercises is necessary for them to complete their mission.

There are six levels in the game, each designed to introduce a different element of Zimmerman's (2000) model and the associated learning strategies. Goal setting is addressed in level one, level two focuses on time management, level three emphasizes self-motivation, stress management is covered at level four, level five highlights learning strategies, and level six centers on self-reflection and causal attribution. Each level is divided into two sections: theoretical content relevant to the SRL strategy and four exercises consisting of a knowledge test, a self-evaluation task, and two tasks that are strategy-specific. Before accessing the tasks, participants must first read the theoretical material. Upon finishing all four tasks in a level, learners get a self-regulation pearl, unlock a new level, and advance to a new area in

Regulatia. In the study's second phase, participants' data were evaluated through an online survey conducted on the *Tivian* platform. It took the participants around 12 minutes to complete the questionnaire, measuring two constructs. Usability was evaluated using the ten items of the System Usability Scale (SUS, Brooke, 1996). The Game User Experience Satisfaction Scale (GUESS, Phan et al., 2016) subscales "playability", "narrative", "play engrossment", "enjoyment", and "visual aesthetics" were used to examine user experience. Additionally, we included subscales for "feedback", "challenge", and "knowledge improvement" (Ziagkas et al., 2020), resulting in 49 items in total for this construct. For all measurements, a four-point Likert scale was utilized (1 = "*strongly disagree"*, 4 = "*strongly agree"*). With the exception of the "challenge" scale, all scales' levels of internal consistency for the sample ranged from acceptable to excellent. At the end of the questionnaire, there were two open-ended questions that allowed the participants to provide their feedback on the prototype's strengths and weaknesses. "*What did you like about Regulatia?*" was the first question, and "*What did you not like about Regulatia?*" was the second. Using *SPSS*, one-sample *t*-tests, and descriptive analyses were performed to investigate usability and user experience. A significance level of α =.05 was proposed for all statistical tests. A qualitative analysis was done on the game's advantages and disadvantages.

4.3.3 Results

High usability of the game and moderate to high scores on all user experience subscales are indicated by the descriptive data (see Table 3). There was a substantial difference between the theoretical score mean of 2.5 and the subscales of feedback, knowledge improvement, playability, and visual aesthetics, suggesting a positive user experience with these subscales. There was no significant difference for the subscales narrative, play engrossment, and enjoyment. For feedback, the effect size Cohen's *d* was low; however, for playability, visual aesthetics, and knowledge improvement, it was high.

Table 3

Descriptive Statistics and Results of the One-Sample t-tests

Scale	Min	Max	*M* (*SD*)	*t*(30)	*p*	Cohen's *d*
System Usability Scale (SUS)	52.50	87.50	71.53 (12.04)	-	-	
Feedback	1.50	4.00	2.77 (.60)	2.53*	.08	.45
Knowledge Improvement	2.00	4.00	3.02 (.56)	5.11**	<.001	.92
Playability	2.22	3.89	3.16 (.43)	8.44**	<.001	1.52
Narrative	1.29	3.43	2.47 (.56)	-0.25	.401	-.05
Play Engrossment	1.20	4.00	2.60 (.71)	0.78	.220	.14
Enjoyment	1.20	4.00	2.70 (.75)	1.51	.071	.27
Visual Aesthetics	1.00	4.00	3.08 (.72)	4.43**	<.001	.80

Note. * = $p < .05$, ** = $p < .001$, Min = minimum, Max = maximum, *SD* = Standard deviation, Range SUS = 0-100, Range user experience scales 0-4.

The responses to the open-ended questions were grouped to assess the game's strengths and weaknesses. We identified eight distinct categories based on the responses to the question, *"What did you enjoy about Regulatia?"*. These categories included graphical design, narration, learning, self-reflection, content and structure, motivation, and task type. The game's graphical design, which includes all visual representations like characters, graphics, and color scheme, was the most often mentioned category (*n* = 16) and strength of *Regulatia*. The narrative was praised for being understandable. Five players thought the game's content was good for imparting knowledge. Participants also appreciated that the game promotes introspection regarding in-game achievements.

We identified nine distinct categories based on the responses to the question, “What did you dislike about *Regulatia*?", representing the game’s weaknesses. These categories included scope and complexity, graphical design, technical problems, text design, instruction, feedback, progress indicators, navigation, and task type. The scope and complexity of the game was Regulatia's most commonly mentioned weakness (*n* = 9). Six participants thought the graphical design was a weakness, despite some participants praising it as a strength. A few participants have expressed concerns about technical issues, particularly issues with scaling brought on by different screen sizes. Participants additionally suggested improving the text design, in-game feedback, and the ability to review completed levels and see an overview of the levels.

4.3.4 Discussion

To encourage SRL in pre-service teachers, Study III assessed the usability and user experience of *Regulatia*, an immersive web-based educational game. According to the findings, *Regulatia* is thought to be user-friendly and to elicit a positive user experience. However, there is still an opportunity for improvement in terms of play engrossment, narrative, and enjoyment.

Users did not report either a positive or negative experience with the game, as evidenced by their assessments of the narrative, play engrossment, and enjoyment, showing no significant difference from the theoretical scale mean.

The narrative’s fractional presentation during gameplay may be the reason for the non-significant result. The game's exercises break up the narrative, which could counteract any beneficial effects. It was also more difficult for the users to assess the narration because they had only completed one level of the game and had never seen the entire story. Play engrossment may have also been adversely affected by the narrative's perception (Adams, 2004). According to Cairns et al. (2014), play engrossment falls into the second stage of immersion in Brown and Cairns' (2004) model, which involves attention and emotional connection. The participants' moderate play engrossment may indicate that they are still in the first immersion stage, which consists solely of the time and effort required to play the game. Consequently, it may not have been appropriate to evaluate the users' gaming experience solely based on play engrossment; instead, the three stages of immersion should be investigated in the future. Although there is space for improvement in this area, the results do not point to a lack of enjoyment. In order to increase the likelihood that users will play the game again, enjoyment is a crucial construct that should be taken into account when developing educational games (Boyle et al., 2012).

The qualitative analysis identified *Regulatia's* strengths as the graphical design, the depth of the narration, and the type of knowledge imparted. The text design, technical issues, and scope and complexity were identified as weaknesses. The sample is one limiting factor, as it only includes individuals from one German university, which limits how broadly the results can be applied. The possibility of receiving credit for the students' studies may have encouraged people who were not intrinsically motivated to participate, even though a consciousness check was used. Because there was no controlled lab environment for this study, participants used their own devices and conducted the study in their homes, which allowed for unpredictable effects from the learning environment. Furthermore, learners did not need to correctly complete the exercises in order to advance in the game, so it was up to the students to deliberately complete the tasks. An overview of the learners’ task success or required tasks might be included in a future version to prevent abuse. The current study may have lost data because this aspect of user experience could not be investigated due to the low reliability of the subscale "challenge". Furthermore, it is not possible to conclude from the current data how well the game promotes SRL.

Study III offers the first encouraging findings about the usability of *Regulatia*, which should be evaluated for the entire game in the future, as well as the efficiency of the game in encouraging SRL in pre-service teachers. After evaluating the game's effectiveness in fostering SRL, *Regulatia* could be practically used to teach pre-service teachers. This would raise the standard for teacher education and provide an alternative method for transferring SRL knowledge. Well-informed teachers will pave the way for higher education by inspiring and influencing upcoming generations of students.

4.4 Study IV

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2023). The Effect of Digital Game-Based Learning Interventions on Cognitive, Metacognitive, and Affective-Motivational Learning Outcomes in School: A Meta-Analysis. *Review of Educational Research*, *94*(2), pp. 193-227. https://doi.org/10.3102/00346543231167795

Abstract

Digital game-based learning (DGBL) interventions can be superior to traditional instruction methods for learning, but previous meta-analyses covered a huge period and included a variety of different target groups, limiting the results' transfer to specific target groups. Therefore, the aim of this meta-analysis is a theory-based examination of DGBL interventions' effects on different learning outcomes (cognitive, metacognitive, affective-motivational) in the school context, using studies published between 2015 and 2020 and meta-analytic techniques (including moderator analyses) to examine the effectiveness of DGBL interventions compared to traditional instruction methods. Results from random-effects models revealed a significant medium effect for overall learning (g = .54) and cognitive learning outcomes (g = .67). Also found were a small effect for affective-motivational learning outcomes (g = .32) and no significant effect for metacognitive learning outcomes. Additionally, there was no evidence of publication bias. Further meta-regression models did not reveal evidence of moderating personal, environmental, or confounding factors. The findings partially support the positive impact of DGBL interventions in school, and the study addresses its practical implications.

4.4.1 Theoretical Background, Research Questions and Hypotheses

When DGBL interventions are compared to traditional instruction methods, an increasing amount of research suggests that the former has advantages. After DGBL interventions, there have been increased learning gains (e.g., higher test scores) in domains like STEM education (McLaren et al., 2017) and language learning (Franciosi, 2017). Because well-designed digital games can adjust to learners's needs and help teachers effectively handle heterogeneity in the classroom, they present a creative way to teach students in the classroom (Plass & Pawar, 2020). With digital games, students can create their own learning experiences within the game and benefit from learner-centered pedagogy.

According to earlier meta-analyses, young children and adults who play digital learning games see higher learning gains than those who use traditional instruction methods (Clark et al., 2016). Evidence also supports the beneficial effects of DGBL interventions on behavioral, affective, and cognitive outcomes in the context of elementary school through university (Lamb et al., 2018). Previous meta-analyses, which only included research up to 2015, concur that DGBL can improve learning. Rapid technological development has occurred in the last five years, which the current meta-analysis covers. This has created new technological opportunities for DGBL interventions, such as the application of ever-more complex game mechanics and detailed textures. However, it is challenging to compare current DGBL interventions with those from ten years ago. Thus, there has been a renewed need to examine the results of DGBL interventions in the last few years. Study IV examines only studies published between 2015 and 2020 to create comparability between DGBL interventions and integrate with the most recent meta-analyses. Moreover, it was challenging to apply the results to particular subgroups because the earlier meta-analyses looked at a broad variety of target groups. Study IV focuses on DGBL interventions in the school context because, as previously mentioned, pupils greatly benefit from them.

Thus, the purpose of Study IV is to examine the impact of DGBL interventions in relation to conventional teaching techniques only in the context of schools between 2015 and 2020. The impact of DGBL interventions was determined by deriving distinct categories of learning outcomes (cognitive, metacognitive, and affective-motivational) using *the Integrated Design Framework for Playful Learning* (Plass et al., 2015). Study IV takes into account metacognitive learning outcomes in the analysis that have not been looked at previously in order to expand on earlier meta-analyses. We anticipated positive effects on learning in general (H 1.1), as well as on the SRL components such as cognitive (H 1.2), metacognitive (H 1.3), and affective-motivational learning outcomes (H 1.4), based on the prior meta-analytic findings. Study IV examined the impact of personal factors, learning environment factors, and confounding factors in addition to the main effects of DGBL on various learning outcomes. The objective of this investigation was to derive recommendations for scientific and educational practice regarding the design and implementation of digital games. The variables that were taken into account in the various categories were inferred from earlier meta-analyses and from exploratory assumptions. For personal factors, we hypothesized (based on previous findings) that learners' age has no impact on DGBL interventions (H 2.1) and that females benefit more than males from the interventions (H 2.2). For environmental factors, we assumed that multiple sessions lead to higher training gains (H 2.3) and that competitional (H 2.4) or three-dimensional (H 2.5) games are more effective than games without competition or two-dimensional ones. Furthermore, we hypothesized that visually schematic games (H.2.6), games with a narrative (H 2.7), and games with avatars (H 2.8) and digital agents (H 2.9) lead to higher-level learning gains than games that do not include these design elements.

Exploratively, we examined the following research questions for environmental and confounding factors: (1) What is the difference in learning between DGBL interventions with and without additional nongame instruction? (2) What are the differences regarding learning between different DGBL intervention types? (3) How does the playing mode influence the effect of DGBL interventions regarding learning? (4) What influence does the learning domain have on the effect of DGBL interventions regarding learning? (5) What influence does the year of publication have? (6) What influence does the country of data collection have?

4.4.2 Procedure and Methods

To determine study eligibility for synthesis, inclusion criteria were defined before searching. The studies had to fulfill the following criteria: Only studies with a focus on DGBL interventions were considered for the synthesis. Therefore, a complete digital game or simulation, based on the definition by Erhel and Jamet (2013), had to be implemented as an intervention in the studies. Eligible studies had to be published between 2015 and 2020 due to the rapid technological change. To remain the focus on the school context, the participants must attend the grades 1 to 13 and studies must comprise at least ten participants to ensure normal distribution of the effect sizes. Only studies that examined dependent variables representing pupils' cognitive, metacognitive, or affective-motivational learning outcomes with high-level research (pre-post control design) were eligible. Eligible studies must be published in peer-reviewed journals or conference proceedings using English or German language and focus on non-clinical samples. The synthesis only included studies with sufficient statistical information to calculate effect sizes, such as, for example, sample size, *t*-value, or *F*-value. All studies which did not fulfill the inclusion criteria were excluded from the analyses.

The search for eligible literature started in February 2020 and lasted until the end of the year. To ensure a broad sample of studies, databases with different focus in terms of content were consulted, including *PubMed, ProQuest, IEEE, ACM, Web of Science, EBSCOhost,* and *Google Scholar*. The search terms *"Game-based learning", "Simulation game", "Serious game"*, and *"Educational game"* were used, each combined with *"training", "learning"*, and *"education"* correspondingly. Additional filter terms, namely *"undergraduate", "patient", "employees"*, and *"disorder"* were implemented to facilitate the search. In total, seven persons (six research assistants and the first author) were involved in the literature search, making use of a standardized literature search manual.

The selection process was undertaken in three steps based on Clark et al. (2016), applying the inclusion and exclusion criteria. First, the process involved selecting studies by screening their titles across the various databases. This resulted in n = 7,013 studied. Cleared from duplicates, n = 3,120 studies were screened on abstract level for eligibility. The full texts of the remaining studies (n = 381) were considered in a final step, resulting in a final sample of N = 36 studies for the synthesis.

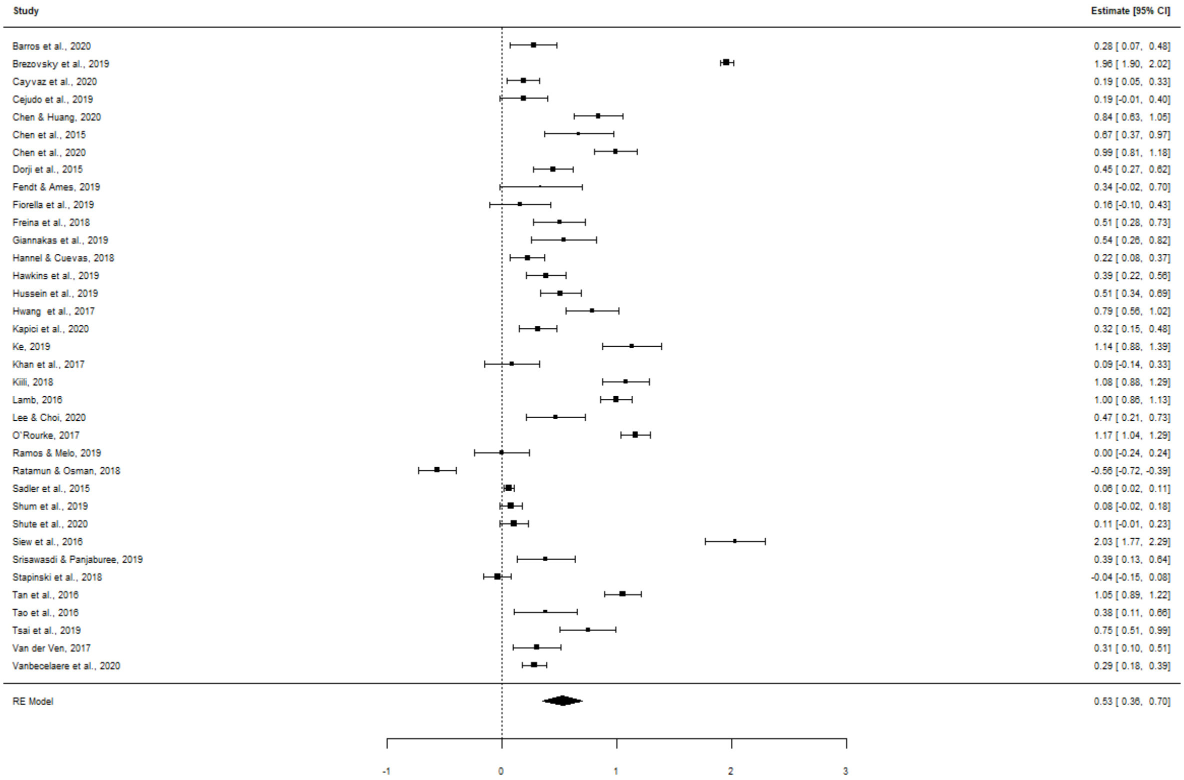
Two independent raters coded the relevant variables and extracted the corresponding statistical parameters for the analyses using a coding guideline manual. To assess the rater agreement, Cohen's Kappa was calculated (Cohen, 1960), resulting in values between κ = .35 and κ = .76, indicating a rater agreement from "low" to "very good". A third rater reevaluated the variables of playing mode and visual realism due to their low consistency. Thus, moderate agreement in all variables could be achieved. Seven experts from educational science categorized the learning outcomes into cognitive, metacognitive, or affective-motivational learning outcomes for each study. Effect sizes were extracted from the studies and converted to Hedge's g with small sample size correction. If a study did not report an effect size, the parameter was calculated based on the provided statistical values. Dependent effect sizes, caused by using the same sample, were coped with calculating the average effect from the partial results. As a synthesis method, the random-effects meta-analysis with the restricted maximum likelihood estimator (REML) was used in *R* (R Core Team, 2020). To investigate the effect of the moderator variables, meta-regression models were computed. The models were evaluated by examining heterogeneity with the *Q*-statistic (Cochran, 1954) and τ^2. Inconsistency was calculated (I^2, Higgins & Thompson, 2002), and Wald-type confidence intervals were provided. In the case of heterogeneity, a prediction interval for the true outcomes was calculated. To assess whether the sample was affected by publication bias, Fail-safe N and selection models were calculated. Additionally, funnel plots were generated for visual examination, and their was symmetry tested with Egger's regression test (Egger et al., 1997).

4.4.3 Results

The literature search yielded N = 36 studies involving N = 7139 participants. Most participants were in sixth grade and had an average age of 11 years. A total of n = 16 studies originated from Asia, while all continents were represented in the sample. The overall learning outcomes analysis resulted in a medium effect size of g = 0.54 (95% CI: [0.37, 0.72], which was statistically significant (z = 6.04, p < .001). According to the Q-test, there was a high heterogeneity in the sample (Q (34) = 3626.72, p < .001, τ^2 = 0.27, I^2 = 98.04 %). Figure 5 shows a forest plot of the overall learning outcomes.

Figure 5

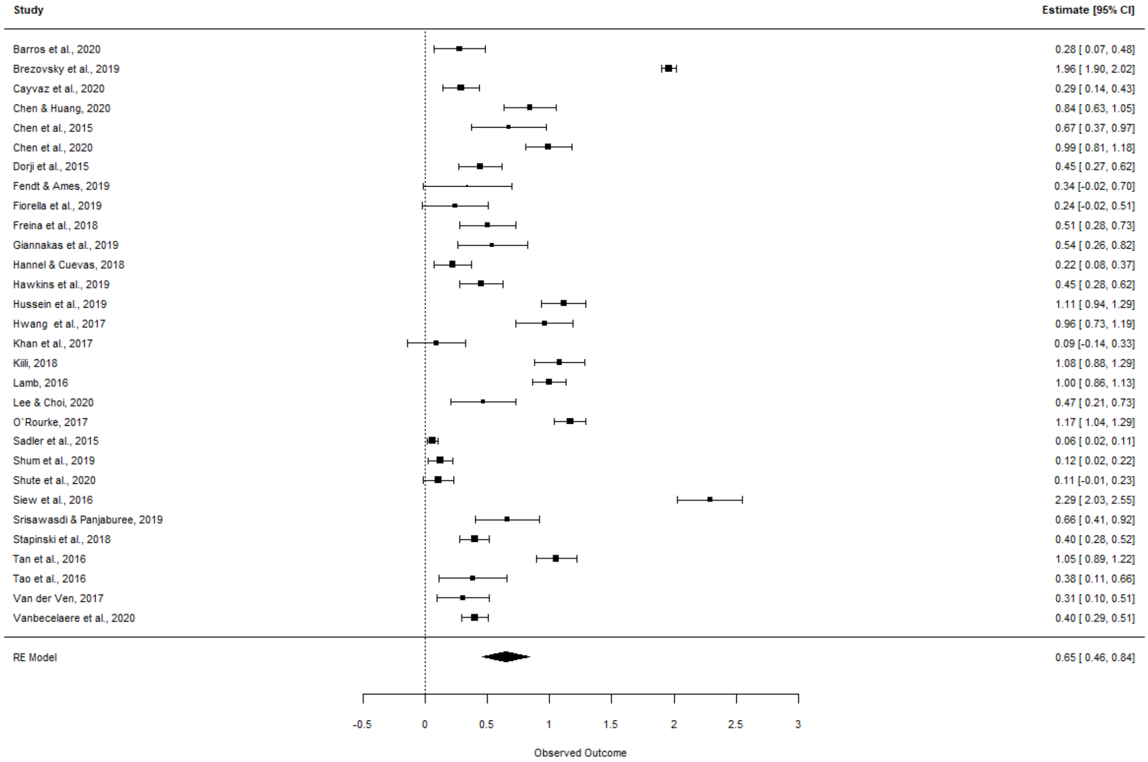
Forest Plot of the Overall Learning Outcomes



The cognitive learning outcomes analysis resulted in a medium effect size of g = 0.67 (95% CI: 0.48 to 0.86), which was statistically significant (z = -6.83, $p < .001$). It appears that the true outcomes are heterogeneous according to the Q-test (Q (28) = 3247.18, $p < .001$, τ^2 = 0.27, I^2 = 98.16 %). Figure 6 shows a forest plot of the cognitive learning outcomes.

Figure 6

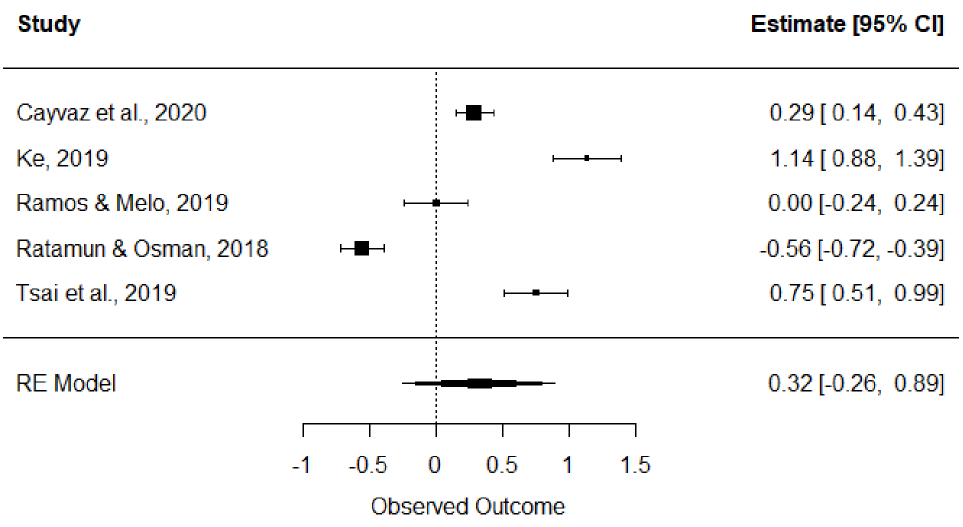
Forest Plot of the Cognitive Learning Outcomes



The metacognitive learning outcomes analysis resulted in an effect size of g = 0.32 (95% CI: -0.26 to 0.89), which was not statistically significant (z = 1.09, p = .276). The true outcomes are heterogenous according to the Q-test (Q (4) = 157.12, p < .001, τ^2 = 0.42, I^2 = 97.62 %). Figure 7 shows a forest plot of the metacognitive learning outcomes.

Figure 7

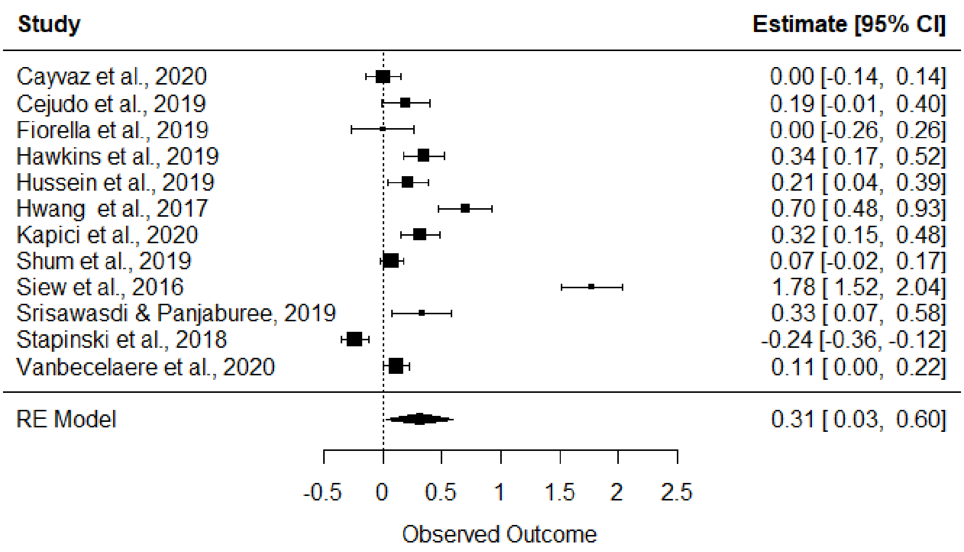
Forest Plot of the Metacognitive Learning Outcomes



The affective-motivational learning outcomes analysis resulted in an effect size of g = 0.32 (95% CI: 0.03 to 0.61), which was statistically significant (z = -2.14, p = .032). The true outcomes are heterogenous according to the Q-test (Q (11) = 240.30, p < .001, τ^2 = 0.25, I^2 = 97.47 %). Figure 8 shows a forest plot of the affective-motivational learning outcomes.

Figure 8

Forest Plot of the Affective-Motivational Learning Outcomes

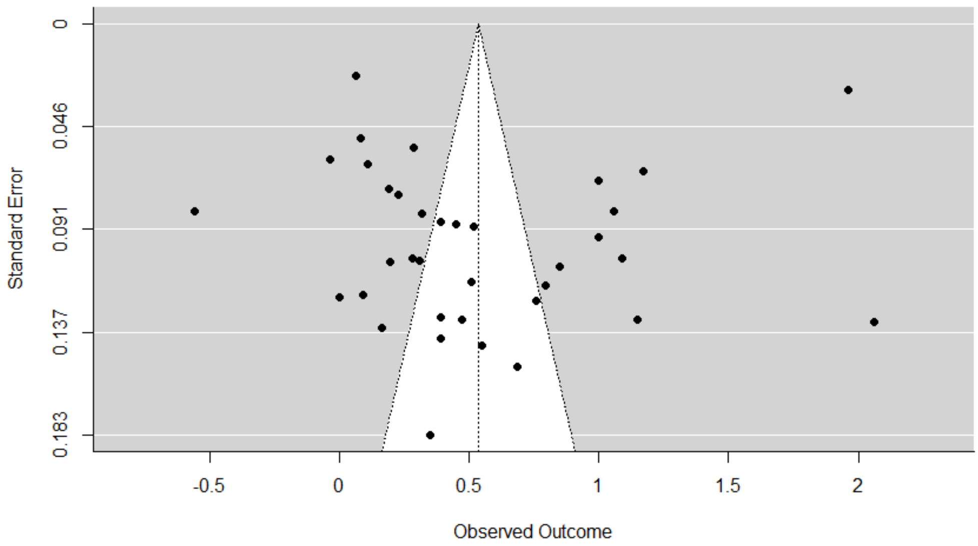


To further examine the estimated effect sizes, moderator analysis was conducted for different learning environment factors (e.g., game type), human factors (e.g., age), and confounding factors (e.g., publication year), which resulted in insignificant findings for all examined moderators, indicating no differences in the single moderators in the sample.

Additionally, publication bias was examined. For the overall learning outcomes, Fail safe N was N_{fs} = 20,745, indicating a robust effect. Figure 9 shows a funnel plot of the estimates. There was no evidence of funnel plot asymmetry in the regression test (z = 0.07, p = .947). A nonsignificant likelihood ratio test (χ^2 (1) = 0.40, p =.528) revealed no significant change in the estimate for the selection model, suggesting that the adjusted model offered no benefit.

Figure 9

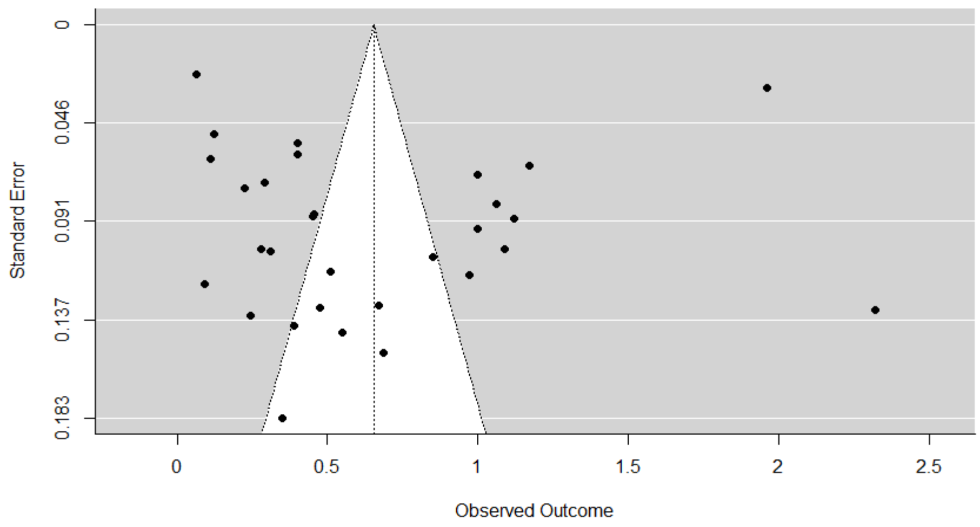
Funnel Plot for the Overall Learning Outcomes



For cognitive learning outcomes, Fail safe N was N_{fs} = 22,796, indicating a robust effect. Figure 10 displays a funnel plot with the estimates. The regression test showed no evidence of funnel plot asymmetry (z = -0.28, p = .778). A nonsignificant likelihood ratio test (χ^2 (1) = 3.70, p = .054) revealed no significant change in the estimate for the selection model, suggesting that the adjusted model offered no benefit.

Figure 10

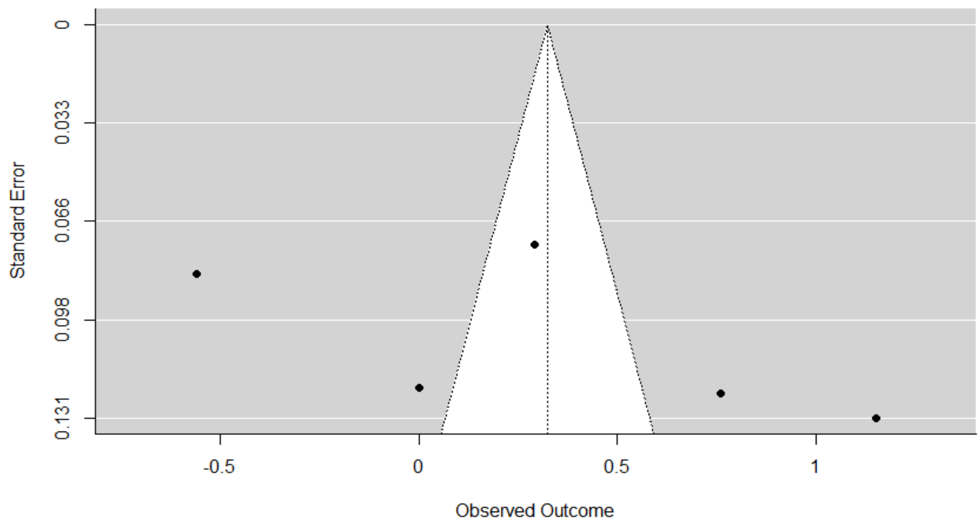
Funnel Plot for Cognitive Learning Outcomes



For metacognitive learning outcomes, Fail safe N (N_{fs} = 49) indicated a robust effect. Figure 11 shows a funnel plot of the estimates. There was no evidence of funnel plot asymmetry in the regression test (z = 1.44, p = .151). A nonsignificant likelihood ratio test (χ^2 (1) = 0.04, p = .845) revealed no significant change in the estimate for the selection model, suggesting that the adjusted model offered no benefit.

Figure 11

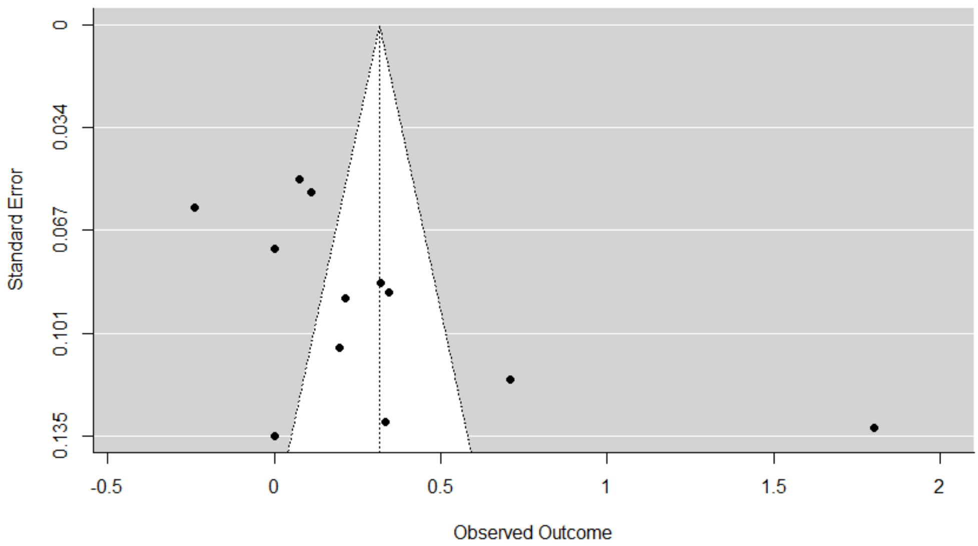
Funnel Plot for Metacognitive Learning Outcomes



For affective-motivational learning outcomes, Fail safe N (N_{fs} = 409) indicated a robust effect. Figure 12 displays a funnel plot with the estimates. The regression test revealed funnel plot asymmetry (z = 2.15, p =.032), which may be a sign of publication bias; however, a nonsignificant likelihood ratio test (χ^2 (1) = 0.07, p =.794) in the selection model indicated no significant change in the estimate.

Figure 12

Funnel Plot for Affective-Motivational Learning Outcomes



To sum up, there was no indication of publication bias for every learning outcome in the sample.

4.4.4 Discussion

Study IV aimed to examine the effects of DGBL interventions in the school setting in comparison to conventional teaching techniques. Additionally, we examined the potential impact of various environmental, personal, or confounding factors on the efficacy of DGBL interventions. Compared to conventional teaching approaches, the results show that DGBL interventions result in better overall learning. This outcome is consistent with earlier meta-analytic data (e.g., Clark et al., 2016; Wouters et al., 2013). A medium effect on learning was discovered for cognitive learning outcomes, representing most studies in the sample. Lamb and colleagues (2018) also discovered a medium effect (*d* = .67) of DGBL interventions on cognitive outcomes, which is consistent with the present result.

Because there were not enough studies measuring metacognitive learning outcomes (*n* = 5), there was not enough test power to confirm the hypothesis that DGBL interventions improve these outcomes. Owing to the great variation in game designs, we discovered a minor impact of DGBL interventions on affective-motivational learning outcomes. According to De Freitas et al. (2018), games must be carefully crafted to be engaging and motivating, with well-integrated learning materials that don't overpower the fun game mechanics. Affective-motivational learning in our sample may have been impacted by the fact that not all DGBL interventions were able to strike the right balance between learning and gameplay.

The impact of DGBL interventions was not significantly influenced by confounding, personal, or environmental moderators.

Because the number of male and female participants in the included studies was evenly distributed, it was not possible to test the effect of gender on DGBL interventions. Furthermore, the effectiveness of DGBL interventions was unaffected by the number of sessions or by using competitive or non-competitive environments. It is surprising that the current meta-analysis found no evidence of higher learning gains from competitive games compared to non-competitive games, as Abdul Jabbar and Felicia (2015) noted in their systematic review that competition in games was "a gameplay element that could emotionally and cognitively engage players and could have a significant impact on learning" (p. 764). According to the current results, there appears to be no discernible difference in the effectiveness of DGBL interventions based on the dimensionality of the game being used. A similar lack of moderating effect was observed for digital agents, avatars, narrative, and visual realism. There is no conclusive evidence, but there is a trend at the descriptive level suggesting that DGBL interventions featuring digital agents, avatars, and a story perform better than those without these elements. No significant effect of additional nongame instruction, game type, playing mode, or learning domain was found for the exploratory research questions. Moreover, there was no confounding influence on the results from the publication year or the nation where the data were collected.

The extremely high heterogeneity of the sample may have contributed to the unexpected findings for the hypotheses and research questions. The DGBL interventions might diverge excessively from one another, complicating the analysis and producing unhelpful outcomes. Additionally, the very small size of some of the analyzed subgroups might have made it difficult to find any meaningful differences. We looked at the robustness and impact of publication bias in the current analyses because they were based on published literature. Egger's regression test, selection models, Fail safe N, and funnel plots did not reveal any publication bias.

5 General Discussion

The following chapters summarize this doctoral thesis's findings based on the four studies conducted. Moreover, the studies' limitations are addressed, and both scientific and practical implications are deduced. The last chapter provides a conclusion.

5.1 Summary of the Findings

The current doctoral thesis aimed to examine SRL in digital learning environments, focusing on its double role as a prerequisite for digital learning and being an improvable competence in pre-service teachers as well as pupils. Three empirical studies and a meta-analysis were conducted to meet the thesis's objective. As a first step, SRL's role in technology acceptance as a prerequisite for digital learning was examined (Study I) by using structural equation modeling to integrate SRL as an external variable in the TAM (Davies, 1989). Study II-IV examined SRL as an improvable competence. In order to better understand how to enhance SRL in pre-service teachers and students, Study II used LPA to analyze the SRL profiles of pre-service teachers in two distinct digital learning environments. An educational game was developed as a follow-up to improve pre-service teachers' ability to learn independently (Study III). In Study IV, a meta-analysis was conducted to determine how beneficial digital educational games are for students when used in a classroom setting.

5.1.1 Self-Regulated Learning as a Prerequisite for Digital Learning

Study I contributes to examining how SRL functions as a prerequisite for digital learning. As described in Chapter 2.3, SRL is essential for effective learning in digital environments and has therefore been considered as an outcome of technology acceptance in the TAM before (Schlag & Imhof, 2017), but not as an external factor that impacts technology acceptance directly. To replicate the established results of the TAM (e.g., Rosli et al., 2022), PU, PEU, attitude toward e-learning, and behavioral intention to use e-learning were implemented in the research model as core TAM variables. Self-efficacy with digital media, affinity for technology, SRL with cognitive, metacognitive, and motivational components, and prior experience with e-learning were implemented as external variables. Since the component structure of SRL in TAM has not yet been examined, this adds to the body of evidence supporting its significance in technology acceptance. Structural equation modeling in R with item parceling was used with three parcels per factor for all constructs except for SRL.

Building three facet-representative parcels represented the three components of SRL, taking SRL's multidimensional nature into account. Furthermore, Study I considers SRL as an external factor in TAM and not as an outcome. This represents another approach to integrating SRL into the model and considering SRL as a prerequisite for digital learning. We assumed that the TAM is replicable for German-speaking students, confirming the positive relations of the core TAM variables. We also hypothesized that the external variables influence PU and PEU directly. The findings revealed that the core TAM could be replicated for our sample, except for the positive relation of PEU and PU. This means the TAM is also valid for university students' technology acceptance regarding e-learning environments. The findings replicate and strengthen TAM's established position to predict students' technology acceptance (Rosli et al., 2022).

Although well examined, self-efficacy with digital media and prior experiences did not influence e-learning acceptance in the proposed structural model. Prior studies focused on computer self-efficacy, which proved an influential external factor in TAM (Al-Adwan, 2020; Ibrahim et al., 2017; Punnoose, 2012). With self-efficacy with digital media, the effect could not be replicated and will have to be examined with an adapted questionnaire in the future. Prior experience with e-learning could also not be confirmed as an external factor in the model. This finding contradicts the numerous results that support prior experience with e-learning as an external factor in TAM (e.g., Leong et al., 2018; Liu et al., 2010; Ros et al., 2014). What has to be mentioned is that the previous findings stemmed from the period before the COVID-19 pandemic when the use of e-learning environments was present but to a much lesser extent than during the pandemic. This is mainly due to forced online schooling, which was unavoidable then. Studies with prior experience with e-learning in the TAM after the pandemic must still be conducted. The recent findings of Study I raise the question of whether prior experience with e-learning is still a valid external factor to consider. This calls for studies examining this phenomenon and the role of previous experience in more detail after the pandemic.

As predicted, external factors positively correlated with PEU and PU were found to be the affinity for technology and SRL. University students will have a more positive perception of PEU and PU levels in e-learning environments in proportion to their level of self-regulation proficiency. The competencies that are necessary for learning in digital environments, such as goal-setting and monitoring, are included in SRL (Broadbent & Poon, 2015). Consequently, it makes sense that those who utilize SRL frequently believe that e-learning is more practical and easier to use. Better learning outcomes have resulted from their prior development and maintenance of coping mechanisms for e-learning environments. The findings support the hypothesis that undergraduate students who are open to utilizing new technologies and interested in them also think that e-learning environments are practical and straightforward to use. Conversely, students who detest technology will refrain from using e-learning.

In conclusion, Study I provides a first insight into SRL's role in technology acceptance and suggests that SRL is an important factor influencing the perception of e-learning environments. Therefore, SRL is a prerequisite for digital learning and should be addressed with SRL training interventions.

5.1.2 Fostering Pre-Service Teachers' Self-Regulated Learning Digital Environments

Study II contributes to fostering pre-service teachers' SRL with e-learning, whereas Study III provides a first step to fostering pre-service teachers' SRL with DGBL. Pre-service teachers serve as multiplicators of SRL for their students in the classroom, as discussed in Chapter 2.4.2. According to Ng (2015), digital learning environments offer pre-service teachers a flexible and ideal way to develop self-regulated learning strategies and create optimal learning conditions. Each student's unique needs should be considered when creating digital learning environments. Individual differences in SRL among learners are still poorly understood, and the number of profiles provided by prior studies that analyzed student SRL profiles has varied. Furthermore, the effects of various learning environments (such as synchronous and asynchronous learning) and pre-service teachers as a particular target group have been disregarded. Because of this, Study II seeks to support SRL by examining the individual differences of pre-service teachers in two distinct learning environments (synchronous and asynchronous). The results show three distinct SRL profiles of pre-service teachers: a low, a moderate, and a high profile. This aligns with the results by Heikkilä et al. (2012) and Muwonge et al. (2020) who also identified three profiles for pre-service teachers SRL. The low-profile individuals seemed to benefit the most from the training regarding using SRL strategies, indicating a compensation effect for this group.

All profiles demonstrated a considerable increase in declarative SRL knowledge; nonetheless, the low profile scored substantially lower than the moderate and high-profile groups. The results revealed no significant differences in SRL strategy use but for declarative SRL knowledge between asynchronous and synchronous learning environments. Compared to the synchronous seminar condition, participants in the asynchronous e-learning condition demonstrated greater training gains in declarative SRL knowledge, presumably due to more time for reflection and in-depth information processing (Lucas et al., 2014). Overall, the findings point to the possibility that asynchronous learning environments, which are better suited for in-depth and complicated subjects, are better for imparting SRL knowledge.

In conclusion, Study II shows that pre-service teachers with various SRL profiles can benefit from SRL training in e-learning environments. This is especially true regarding strategy use for individuals with low SRL profiles. The training effectively improves declarative SRL knowledge, notably in the asynchronous environment.

Study III assessed the usability and user experience of *Regulatia*, an educational game to foster SRL in pre-service teachers. The study contributes to developing the first educational game to foster SRL for pre-service teachers. The research questions comprised whether *Regulatia* is user-friendly, how learners perceive the game, and the assessment of the game’s strengths and weaknesses. The results show that people believe *Regulatia* is user-friendly and provides a satisfying user experience. Users' evaluations of the narrative, play engrossment, and enjoyment did not significantly deviate from the theoretical scale mean, suggesting that users did not report a positive or negative experience with the game. According to the qualitative analysis, *Regulatia's* strengths are the graphical design, the narration's depth, and the knowledge imparted. *Regulatia’s* weaknesses are the text design, technical issues, and scope and complexity.

In conclusion, Study II presented an effective e-learning environment to foster declarative SRL knowledge, especially among pre-service teachers. Study III offered the first encouraging insights about the usability of *Regulatia*, which could provide the basis for an effective educational game to foster SRL in pre-service teachers in the future. Both studies contribute to developing effective SRL training for pre-service teachers in digital learning environments.

5.1.3 Effectiveness of Game-Based Learning in the School Context

Study IV contributes to examining the effect of DGBL in the school context to provide a basis to foster SRL with educational games in the classroom. Previous meta-analyses have demonstrated that DGBL improves learning across the board, from elementary school to university (Clark et al., 2016; Lamb et al., 2018; Wouters et al., 2013). However, only research conducted up until 2015 was included in these studies. In the past five years, technological development has advanced quickly, creating new opportunities for DGBL interventions. Therefore, Study IV investigates the effects of DGBL interventions solely in the context of schools, in comparison to traditional teaching methods in studies between 2015 and 2020. Using the *Integrated Design Framework for Playful Learning* (Plass et al., 2015), separate categories of learning outcomes that represent SRL's components (cognitive, metacognitive, and affective-motivational) were derived to assess DGBL interventions' effectiveness. In order to build on previous meta-analyses, Study IV considers metacognitive learning outcomes that have not been examined before. Positive effects on learning outcomes related to motivation, metacognition, and cognitive learning were hypothesized. Additionally, Study IV looked at the influence of confounding, personal, and learning environment factors.

Random-effects meta-analysis revealed a medium overall effect for DGBL as well as for cognitive learning outcomes. For affective-motivational learning outcomes, a small effect was found. These results are in accordance with previous meta-analyses (e.g., Clark et al., 2016; Wouters et al., 2013), which suggest an advantage of DGBL interventions over traditional instruction methods. However, the small effect on affective-motivational outcomes is surprising because digital games are often characterized as motivational (Chang et al., 2017). This assumption does not seem to apply to all educational games in the sample, illustrating that finding the right balance between learning content and motivating game elements is crucial while designing educational games. If there is an imbalance, educational games can quickly bore learners, which is criticized as "chocolate-covered broccoli" in game design (Bruckman, 1999; DiSalvo, 2015).

Due to a lack of studies, no significant effect could be found for metacognitive learning outcomes, calling for more studies that focus on metacognitive learning outcomes. Moreover, no significant influence of the proposed personal, environmental, and confounding moderators could be found in the meta-regression models.

Since positive effects on the effectiveness of digital games in general and cognitive as well as motivational outcomes have been shown, it seems promising that SRL can also be promoted with digital learning games for students, which should be analyzed in future studies. To do this, it is necessary to design a game that is suitable for the children's needs.

In conclusion, Study IV shows that DGBL interventions are also effective in the school context, providing a basis to develop games that specifically promote SRL in the classroom to implement another direct or indirect method to foster SRL in an early age.

5.2 Limitations

Even though every study provides further research findings, the present doctoral thesis is also subject to limitations. The shared limitations of empirical studies I-III are presented collectively, and then the most critical specific limitations of empirical studies I-III and the meta-analysis in Study IV are discussed.

One limiting factor for all three empirical studies is the sample. In Study I, the sample size was just enough for examining structural equation models, and in Study II, the sample size was also relatively small for conducting an LPA. Spurk et al. (2020) recommended at least 500 participants for an accurate categorization in the LPA—challenging to realize—calling for further investigations with a larger sample. Furthermore, the samples in studies I-III all consist of German-speaking participants, in studies II and III, even from the same university, which restricts the generalizability of the findings. For future studies, a larger and cross-national sample would be desirable. In Study II, participants came from different courses at the same university with different course teachers. This nested data structure may have impacted the findings but was not considered in the analyses. To improve this, hierarchical mixture models can be used in subsequent studies (Vermunt & Magidson, 2005).

Another collective limiting factor is that the data is based on self-report collected via questionnaires. Self-reporting as the sole source of the evaluated data presents a methodological bias since the data may be skewed or purposefully faked to fit social desirability standards. It is possible that some people provided false information in their answers to the questions. Moreover, self-reporting is limited to conscious processes. It can be used to evaluate every aspect of SRL, including affective, cognitive, physiological, and behavioral processes because they can be reported appropriately (Pekrun, 2020). Given that SRL can be viewed as a process or as its components, offline and online measures and quantitative and qualitative standards are the categories into which Wirth and Leutner (2008) divided SRL measurement. According to Foerst et al. (2017), offline standards assess SRL's components, whereas online standards assess SRL's process character. While qualitative standards suggest that learners with high SRL skills must fit the strategies they apply to the particular learning situation and exercise, quantitative standards suggest that increased SRL strategies equate to improving SRL (Rovers et al., 2019). Self-report questionnaires are categorized as offline measures that rely on quantitative standards and are often used (Roth et al., 2016) but neglect SRL's online and qualitative measures, revealing a limitation of SRL questionnaires. A mixed-methods approach between online and offline measurements with different standards, for example, think-aloud measures (Roth et al., 2016) or strategy knowledge tests (Dörrenbächer-Ulrich et al., 2024), would have increased the robustness of the results (Pekrun, 2020).

A third joint limiting factor is the measurement instruments used. In Study I, SRL was evaluated for learning in general rather than in the e-learning context. This may have affected how well the scale aligned with the other scales being studied, which were designed for online learning. In Study II, the reliability of the cognitive subscale of SRL is questionable, potentially leading to unreliable measurements (van Griethuijsen et al., 2015). Furthermore, in Study III, the low reliability of the user experience subscale "challenge" meant that this aspect could not be investigated, potentially resulting in the loss of important information. Scales that consistently measure the relevant constructs in the online context should be used in future research to ensure a more reliable measure.

One specific limitation of Study I is that the data distribution for some constructs was non-normal. Item parceling was chosen as a solution to address this problem. It should be noted that item parceling is a contentious topic because aggregating individual items results in information loss (Little et al., 2013). Before using item parceling, carefully considering the benefits and drawbacks is advisable. Another limitation is that low factor loadings have resulted in a significant dropout rate of items that represent the motivational component of SRL. This could have led to this subscale's omission of significant motivational aspects. Future studies should, therefore, examine the motivational component more closely based on the TAM to provide further insights into its role in technology acceptance. Furthermore, the vague definition of e-learning by Clark and Mayer (2016), which served as one theoretical foundation, is another limitation of Study I. Microlearning units, simulations, and instructional videos are just a few examples of the diverse instructional methods that form e-learning, making it a heterogeneous construct. The results that were received may have been distorted by the participants' perceptions and interpretations of the various e-learning components. Prospective studies could focus on either one specific type of instructional method in e-learning environments at a time or choose a more precise definition for e-learning to ensure participants have the same idea of e-learning. Lastly, Study I makes no allowances for concluding the real use of e-learning environments; instead, it merely makes the assumption that behavioral intentions will result in actual use. Due to this, actual use should be considered a variable in prospective research.

One specific limitation of Study II is the implemented e-learning environment. Even though the e-learning course lasted six weeks, students could finish it sooner. Some students may have completed the course ahead of schedule, and others may have put off learning the material until the very last days. The assignments that needed to be submitted through the e-learning platform were visually checked to prevent cheating in course completion. However, the content was not assessed for quality, meaning learners may have only completed the tasks at a surface level. To improve this, the e-learning environment could have time restrictions and a quality check of the assignments in the future. A last limitation is the small number of subjects in Profile 1 (low SRL profile), which may not represent the entire pre-service teacher population, limiting the findings' generalizability. It is important to note that the approach only covers specific levels of SRL and does not include the full continuous spectrum of SRL.

In Study III, the participants could receive credit for their studies, leading to involuntary participation and low internal motivation to participate consciously. To improve this in the future, a study without credit can be conducted to ensure completely voluntary participation and intrinsic motivation. Another limiting factor was the uncontrolled learning environment during the study because the students participated with their own devices and were remote from home. This prevented controlled laboratory conditions for the experiment, which could be implemented in prospective studies. Furthermore, the learners did not need to complete the exercises to advance in the game correctly, so it was up to the students to deliberately complete the tasks. There is also the limitation that Study III does not address, which is whether the developed game can support SRL in pre-service teachers, as it only considers game design and usability. As a result, it is not possible to conclude from the current data whether the game is beneficial in promoting SRL which will have to be examined in a future study.

For Study IV, the conducted meta-analysis, several limitations must be addressed. When working with data derived from a literature search, it is always possible that some studies may not have been found. This could have happened because the various databases offered different ways to narrow down the search results. Furthermore, the data may have a language bias because the authors are limited to reading papers in English and German. In terms of the coding process, the visual realism of the papers was assessed using their graphics. It was difficult for the raters to determine which category of visual realism the game belonged to based on the quantity of photos. The chance that games were incorrectly categorized because they lacked images cannot be completely ruled out, as this could potentially impact the meta-regression findings. The limited number of studies evaluating metacognitive learning outcomes is another limitation of Study IV; in the current meta-analysis, only five studies were available to examine how DGBL interventions affected those outcomes. As a result, care should be taken when interpreting the data, and future research should continue to concentrate on how DGBL interventions affect metacognitive learning outcomes. Because the primary studies lacked some moderator information, the sample size was smaller for the moderator analyses, which increased the likelihood of moderator effects being detected. Furthermore, since the number of sessions does not indicate how long the intervention lasted—for example, five sessions may have taken place in a week or three—the moderator variable "number of sessions" has little informative value. More accurate variables than the number of sessions should be considered in future research: the precise duration.

5.3 Implications

Apart from the limitations described above, this doctoral thesis also provides findings with both scientific and practical implications, which are presented in the next chapters.

5.3.1 Measurement of Self-Regulated Learning in Digital Environments

First, all presented empirical studies are based on self-report, which can be biased due to socially desirable answers (Van de Mortel, 2008). A mixed-method approach for future studies would be reasonable to compensate for this bias (Koivula et al., 2019). With pure self-report, respondents tend to lie to make themselves look better or answer in a way they believe is expected of them. The inclusion of multiple sources that do not only rely on self-report, such as external judgment or the inclusion of objective data, can ensure a more reliable measurement of SRL in online environments. Learning analytics is an objective method that utilizes learner data from various learning environments to understand and draw conclusions about how learners engage in online courses (Viberg et al., 2020). This approach evaluates the traces that students leave behind while completing an online course, offering a non-intrusive way to gather information compared to intrusive methods like self-reporting. For example, log files, the recording of behavior or clicks, could represent a measure to map SRL processes. In addition, utilizing *Moodle* as a training platform enables log and process data generation. This can provide a more comprehensive understanding of SRL by offering multiple measurement points, which allows for detecting profile changes throughout the intervention. Research shows that when it comes to predicting achievement, traces are more reliable than self-report measures (Rovers et al., 2019). Learning analytics can serve as a tool to assess SRL strategy (Prasse et al., 2024) and simultaneously improve learners' activities by providing insights, e.g., through dashboard visualization (Matcha et al., 2020). It is essential to mention that data for learning analytics is difficult to assess and interpret (Viberg et al., 2020), and its potential to foster SRL simultaneously is still unclear (Heikkinen et al., 2023).

In addition, Study I evaluated SRL in a general learning context rather than in the specific e-learning context. It would be beneficial to assess SRL with a context-specific measurement tool (Du et al., 2023). Study II also found that the reliability of the cognitive subscale of the SRL questionnaire is questionable, which could lead to unreliable measurements (van Griethuijsen et al., 2015). The low factor loadings have caused a significant dropout rate of items that represent the motivational component of SRL. The instrument should be revised and improved. The first questionnaires are available for the specific measurement of SRL in e-learning environments, e.g., the Online SRL Questionnaire (Barnard et al., 2009) or the Self-regulation for Learning Online Questionnaire (Broadbent et al., 2023). For DGBL, which contains its own specific characteristics that must be taken into account when measuring SRL, there are no self-report questionnaires that measure SRL in the specific context of DGBL to the author's knowledge. Further research and the development of specific test instruments are needed here. Digital games also open up the possibility of learning analytics.

Regardless of the measuring instruments used, care should be taken to ensure that cross-sectional and longitudinal measurements are taken. This includes a follow-up measurement after the post-test to detect sleeper effects, in which learners need more time to develop SRL strategies after an intervention. In SRL, these are caused by the delayed learning effect because there is first interference with known strategies before learning new ones (Lüftenegger et al., 2016).

5.3.2 Recommendations for Fostering SRL in Digital Learning Environments

Pre-service teachers play a crucial role in demonstrating how to use learning strategies in the classroom for their future students (Peeters et al., 2014). In order to effectively teach students about using SRL strategies, pre-service teachers first need to develop their own SRL skills (Karlen et al., 2023). This thesis strengthens the assumption that SRL is a promotable competence, and therefore, based on the findings, recommendations for future learning environments to foster SRL are deduced.

As demonstrated in Study I, it is crucial to consider individual SRL profiles and create adaptive training and learning environments to meet learners’ needs (Molenaar, 2022). Based on the findings of Study II, asynchronous learning environments seem suitable for declarative SRL knowledge improvement, and for SRL strategy use, both synchronous and asynchronous learning environments are adequate. Concerning this matter, pure asynchronous learning environments or a combination of asynchronous and synchronous learning parts (Amiti, 2020; Giesbers et al., 2014) seem reasonable to promote SRL strategy use and declarative SRL knowledge simultaneously. A combined use would ensure optimal utilization of both types of communication. Pre-service teachers need to understand that SRL can improve students' academic success and help them support their students' future learning efforts (Fischer & Dignath, 2024). Study II moreover revealed the need for time and access restrictions for the learners, as well as quality checks of submissions, to ensure a conscious processing of the learning tasks. To prevent abuse of the learning environments, a requirement or an overview of the learner's success in the task could be implemented and integrated into future learning environments of Study II and Study III.

Study IV shows that interventions with digital games in the classroom are effective and can cause positive learning effects. For prospective research, it is essential to create motivating and exciting games. To accomplish this, future DGBL interventions must balance intrinsic or extrinsic game elements with well-integrated learning content. Game designers need to consider which aspects of the game are appropriate for each learning goal of the intervention. Since every student has different needs and preferences during learning, it is impossible to make a general recommendation for fitting a DGBL intervention to every student. Consequently, learning games that adjust to the needs of students may be the answer. However, it takes money and effort to develop DGBL interventions in general, and adaptive games in particular. When feasible, researchers should use games accessible to the general public if they align with the learning objective. Future research should look into which aspects of game design contribute to the beneficial effects of DGBL, as it is currently unclear. Future research on DGBL interventions ought to compare various game versions and concentrate on particular aspects of game design in isolation.

5.3.3 Further Scientific Implications

In future studies on SRL in digital learning environments, it is important to consider whether prior experience remains a relevant variable. Prior experience may not be a valuable variable for e-learning environments due to the widespread adoption forced by the COVID-19 pandemic. However, it could still be relevant in game-based learning, where it is less commonly used.

Given that Study I could not make any statements about the actual use of e-learning, this could be examined in future studies and research models.

Study II only covers specific levels of SRL and does not include the full continuous spectrum. Therefore, future research could include continuous SRL profiles rather than distinct stages.

As a result of Study III, it is recommended that future studies be carried out in a laboratory setting to maintain a controlled environment and minimize potential confounding factors that may arise in a home environment. Additionally, due to the limited understanding of the game's effectiveness, it is suggested that further research investigate the efficacy of *Regulatia* in terms of learning outcomes using a randomized pre-post-control design and compare it to other forms of digital learning. For future research, extending the training period to either increase the use of SRL strategies or decrease the training content is recommended.

To improve Study IV and ensure a broader use of literature, unpublished work, so-called grey literature, could be included in future meta-analyses (Hopewell et al., 2005). Moreover, a more specific measurement should be defined for the coding of visual realism. In doubt, the authors should be addressed to gather more specific information about the implemented DGBL interventions. Study IV further revealed a lack of studies considering metacognitive learning outcomes in DGBL interventions, calling for more studies that address this topic.

Regarding the moderator variables, since the number of sessions does not indicate how long the intervention lasted—for example, five sessions may have taken place in a week or three—the moderator variable "number of sessions" has little informative value. More accurate variables than the number of sessions should be considered moderator variables in future research: the precise duration. Moreover, the year of publication may not make sense because there is no information about the actual time of data collection, the year of data collection should rather be considered, although this is difficult to record. A closer look at the previously mentioned and additional moderators (such as intervention duration and device type), given that the current meta-analysis did not find any moderating effects may also shed light on the efficacy of DGBL interventions. Additionally, it is not possible to generalize the findings of Study IV to all types of DGBL intervention because it only contains games that do not involve augmented or virtual reality. They cannot be compared to games that do not employ these techniques due to the varying levels of immersion (Skarbez et al., 2021). Thus, it would be interesting to see more meta-analytic research on DGBL interventions involving embodiment, augmented or virtual reality.

5.3.4 Practical Implications

The results of this doctoral thesis also allow practical consequences to be derived.

The results of Study I may help remove barriers that keep students from utilizing online learning environments. The results can also increase the probability that students will accept e-learning as a part of their academic path. Teachers need to reevaluate how well they can meet their students' needs in light of the COVID-19 pandemic's effects on distance learning (Fischer & Dignath, 2023). They also need to know what factors help or hinder students' acceptance of and engagement with virtual learning environments. Study I has shown that SRL and affinity for technology are two crucial factors that indirectly influence attitudes toward e-learning via PU and PEU and thus positively influence the intention to use e-learning. Learners with strong SRL skills and a penchant for technology will be more open to online learning. Therefore, it is imperative to introduce explicit strategy use and technology in university courses and in the school context to foster SRL skills and affinity for technology as early as possible. This can be achieved by giving students the chance to use technology in the classroom to help them become less afraid of it and to promote their use of it as a study tool. Enhancing opportunities for mastery experiences can boost students' e-learning confidence and self-efficacy (De Smul et al., 2018). In this context, it is important that teachers are well trained in the use of digital media, as online environments require different methods than analog learning (Fischer & Dignath, 2023). These skills should be an integral part of the teacher training curriculum. Based on the recommendations in Chapter 5.3.2, digital learning environments can be used for this purpose in order to generate a wide range of independent learning in teacher training while at the same time promoting self-regulated learning among teachers, who can pass this on to their students as a model (Peeters et al., 2014).

Study II reveals a need for teacher training, as most participants (60%) were classified as having a low or medium SRL profile, indicating potential for improvement. Furthermore, there was a dissonance between knowledge of SRL and the use of SRL strategies. Although many teachers know what SRL involves, they cannot implement this in their teaching methods. This needs to be counteracted by providing teachers with explicit methods and strategies for teaching SRL in the classroom in order to facilitate the transfer of knowledge and use (Šimić Šašić et al., 2023).

For this reason, Study III created a specific educational game for pre-service teachers and assessed its usability and game design. After examining the entire game at all levels and its effectiveness in fostering SRL, *Regulatia* might be applied practically to teach pre-service teachers to improve the standard of teacher education and provide an alternative approach to

SRL knowledge transfer. Knowledgeable educators will influence and motivate future generations of students while they work, setting the stage for higher education.

Study IV shows that DGBL can be used as a learning tool not only in teacher training, but also directly in the classroom. According to the current literature, thoughtfully created DGBL interventions could encourage students to interact with the materials and, as a result, advance their learning process. Students who are disinterested in traditional learning environments or need to work more independently or cooperatively with other students may find this especially helpful. The significant degree of heterogeneity in the classroom means that teachers are not always able to meet every need of their students. By providing exercises that are sufficiently challenging for the learners, for example, DGBL interventions in the classroom can be tailored to meet their needs and provide adaptive features that enable learning by considering each learner’s own pace. This could support learner-centered pedagogy, which puts the needs of the students first, gives them the freedom to learn at their own speed, and keeps them from giving up or being overwhelmed by demands. As Plass et al. (2015) put it, "graceful failure" (p. 261) is encouraged by DGBL interventions, which provide a secure learning environment that may boost self-efficacy by fostering mastery experiences. Cognitive outcomes appear particularly well-suited for DGBL interventions, meaning teachers can effectively use them to impart knowledge to their students. Additionally, DGBL may also happen during distance learning, providing students who cannot attend classes in person with an alternative learning method. Students do need access to computers and other digital devices, necessitating furnished classrooms and homes. Still, some schools do not have the necessary supplies to implement DGBL. The governance should invest in education and, as a result, give schools and families financial support to increase the potential to offer DGBL interventions in the classroom or at home. Conversely, the effective use of educational games in the classroom requires teachers to be technologically literate (Marklund & Taylor, 2016). Research indicates that educators are eager to employ DGBL interventions; however, they frequently worry about their level of expertise and gaming literacy when it comes to executing DBGL interventions in the classroom (Jong, 2015). This demonstrates the necessity of incorporating various digital media, including digital games, into the teacher education curriculum to promote the knowledge and self-efficacy needed to use them.

5.4 Conclusion

The current doctoral thesis focused on SRL's dual role as a prerequisite and promotable competence for learning in digital learning environments for pre-service teachers and students, which could be confirmed in the results. The findings revealed new insights into SRL's role regarding technology acceptance toward e-learning because SRL was an external factor in the Technology Acceptance Model (Davis, 1989), indicating a higher acceptance of e-learning for university students who show high SRL skills. As a result, SRL should be considered a prerequisite when designing e-learning environments.

Moreover, the findings confirm that SRL is a promotable competence for pre-service teachers. When designing SRL training for pre-service teachers, particular attention should be paid to their prerequisites concerning SRL, as a compensatory effect for pre-service teachers with low skills has been shown, especially for teaching SRL strategy use. For declarative SRL knowledge, SRL training appears equally suitable for all SRL profiles. Accordingly, with the help of SRL training, pre-service teachers' deficits in using SRL strategies can be specifically addressed, and declarative knowledge of SRL can be increased. This is highly relevant, as (pre-service) teachers serve as multipliers for their students in the classroom (Karlen et al., 2023; Peeters et al., 2014) and can, therefore, positively influence their students' learning progress from an early age. As the grades achieved during their school career significantly influence their students' future jobs, (pre-service) teachers have a great responsibility, which may have a life-changing impact. In order to better fulfill this responsibility, teaching staff must be trained explicitly in SRL and how to teach it. Therefore, it would be desirable for SRL to become a mandatory part of the teacher training curriculum in Germany and to be fostered in pre-service teachers early on.

Furthermore, digital learning environments, especially DGBL, seem promising for innovative methods to foster SRL in pre-service teachers. The findings provide first insights into game design to promote SRL. Given that the examination of SRL in DGBL is relatively new, this further drives future research possibilities, such as the investigation of DGBL's effectiveness for SRL training. It was also demonstrated that DGBL can effectively enhance student learning outcomes in the classroom. Here, too, digital learning games could contribute to promoting SRL in the classroom for the target group of students. Because there is still little research available, more research is needed into which game elements can effectively promote SRL in both pre-service teachers and students to equip them with an important future skill such as SRL.

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7 Appendix

Study I:

Barz, N., Benick, M., Dörrenbächer-Ulrich, L. & Perels, F. (2024). Students' Acceptance of E-learning: Extending the Technology Acceptance Model with Self-regulated Learning and Affinity for Technology. *Discover Education*, *3*(114). https://doi.org/10.1007/s44217-024-00195-7.

Study II:

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Study III:

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Study IV:

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