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ORIGINAL RESEARCH

Co-design: From Understanding to Prototyping an Adaptive Learning Technology to Enhance Self-regulated Learning

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Abstract

Self-regulated learning (SRL) is an important aspect of successful knowledge acquisition. Adaptive learning technology (ALT) is a form of educational technology that can improve SRL by offering learners personalized and timely support. Despite the potential of ALT to support SRL, its integration into schools' pedagogical practices remains a challenge. To address this challenge, this study took a co-design approach to develop and implement an ALT in an upper secondary school over three phases. In the exploration phase, we collected and analyzed qualitative data from structured interviews ($n = 14$) and group discussions ($n = 7$) with students and teachers. In the defining phase, we identified problem areas of ALT through a co-design group and formulated suggestions for developments. These suggestions were integrated into the ALT in the shaping phase. The findings showed that the co-design process facilitated better incorporation of the needs of students and teachers into the development of the ALT. Direct integration of user perceptions and descriptions strengthened the connection between ALT and SRL while enhancing the tool's adaptability. Not all suggestions from the co-design group could be implemented into the ALT. In the future, more attention should be given to understanding the interfaces between different groups of actors in the co-design process, particularly in K-12 education contexts.

Keywords Co-design · Self-regulated learning · Adaptive learning technology · Upper secondary school

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1 Introduction

Self-regulated learning (SRL) has garnered significant attention in educational research, policy, and practice (Boekaerts et al., 2000; OECD, 2021; Schunk & Greene, 2018; Zimmerman & Schunk, 2011). Self-regulated learners are those who employ metacognition to assess their abilities and address gaps. They are motivated by personal growth, embrace challenging tasks, and view errors as learning opportunities, adeptly selecting and applying effective strategies when tackling complex problems (Perry, 2013). SRL is increasingly reliant on digital media such as learning platforms, learning management systems, chatbots, and apps (Broadbent & Poon, 2015; Broadbent et al., 2020). This reliance is driven by the digital transformation of education systems (Beller, 2013; Scherer et al., 2019), reflecting the growing significance of educational technology in the learning process.

In this context, adaptive learning technology (ALT) has emerged as a key development (Becker et al., 2018). The primary goal of ALTs is to support students' learning, and SRL specifically, to promote progress (Azevedo & Gašević, 2019). Research into ALT has surged in recent decades (Martin et al., 2020) and the integration of such technologies into pedagogical practices is increasingly prevalent (Molenaar et al., 2021). Questions persist, however, about the technical and pedagogical requirements of ALTs to foster SRL (Xie et al., 2019). In developing educational technology, a central question is how pedagogical agents can best be involved in the development process. The perspectives of teachers and students are particularly important (Könings et al., 2014). One promising approach to tackle these challenges is to democratize the process of designing educational technologies by involving teachers and students (Fleischmann, 2015). This trend has prompted proposals for the implementation of co-design processes in this field (Durall et al., 2020; Durall Gazulla et al., 2023; Mor & Winters, 2007; Roschelle & Penuel, 2006; Treasure-Jones & Joynes, 2018). This study contributes to ongoing discussion regarding how co-developed ALTs can promote students' SRL.

2 Enhancing Self-regulated Learning with Educational Technology: Opportunities and Challenges

Self-regulated learning (SRL) is a complex process involving cognitive, motivational, emotional, and behavioral components (Panadero, 2017). In SRL, learners take an active role in monitoring and controlling their cognitive processes and behaviors to enhance their knowledge and skills (Pintrich, 2004; Winne & Hadwin, 1998; Zimmerman, 2008). SRL is understood as a hierarchically organized, temporal, and adaptive process in which learners conduct task analysis, develop goals, and create plans to solve tasks. Students apply learning strategies to achieve their goals, with motivational and affective factors playing an important role in initiating and sustaining goal attainment. SRL involves continuous monitoring and reflection upon the learning process and goals using metacognitive strategies. The effective use of these strategies depends on the task and the contextual factors of the learning environment (Greene et al., 2021).

Students who effectively manage their learning processes tend to perform better academically (Dent & Koenka, 2016; Jansen et al., 2019; Richardson et al., 2012), have greater self-efficacy (Panadero et al., 2017), and develop higher levels of metacognitive knowledge (Dignath & Veenman, 2021), with an accompanying increase in well-being

(Rodríguez et al., 2022). Contemporary research on SRL focuses more on digital learning environments (Azevedo & Gašević, 2019; Broadbent & Poon, 2015; Kuhnel et al., 2018), a shift that aligns with the ongoing digital transformation in education and the integration of educational technology into school and classroom practices (Costa et al., 2021). The term 'educational technology' refers to digital information and communication tools that improve teaching and learning (Spector, 2013). Adopting educational technology can inform a better understanding of SRL (Winne, 2022). Research indicates that the use of educational technologies in the classroom fosters SRL, improves academic performance, and boosts students' motivation to learn (Nicholson et al., 2022).

ALT provides learners with greater flexibility in practicing SRL by assisting them in tackling learning challenges (Park et al., 2023; Winne, 2017). ALT is a collection of educational software tools and systems that utilize data analytics and machine learning algorithms to offer student tailored learning experiences that reflect their needs, strengths, and weaknesses (Imhof et al., 2020; Nakic et al., 2015). The concept of adaptive learning has a long tradition in learning research and is related to concepts such as personalized learning, student-centered education, individualization, and differentiated instruction (Schmid et al., 2022). ALT promises to personalize and improve education by identifying learning gaps, recommending relevant content, and assessing progress until learning objectives are met (Xie et al., 2019). It offers a range of new opportunities in educational practice and research, driven by the rapid development and uptake of information and communication technology (Scherer et al., 2019).

ALT has been shown to improve SRL (Aleven et al., 2017; Bernacki et al., 2011; Molenaar & Van Campen, 2016). Azevedo and colleagues (2013) showed that ALT facilitated students' SRL by providing scaffolding, offering support, and nurturing cognitive, affective, and metacognitive processes. ALT has also been shown to positively influence students' academic performance and motivation (Faber et al., 2017), and the adaptation of learning behaviors (Molenaar et al., 2021). Moreover, ALT is effective at identifying deficiencies in students' SRL and addressing these by establishing clear learning objectives. In one study, this was achieved through an automated graded learning system, which helped learners evaluate their progress and enabled instructors to deliver timely and tailored feedback (Forsyth et al., 2016).

Despite the evidence supporting the impact of ALT on SRL, some findings indicate a risk of learners not adjusting their learning behavior despite ALT support, potentially leading to dysregulated learning (Azevedo & Feyzi-Behnagh, 2011). This challenge is linked to what Xie and colleagues call "readiness" (2019, p. 13), which relates to whether students' experiences and contexts enable motivation and learning in class. For some learners, poor classroom conditions can hinder the use of ALT to regulate learning and modify behavior. Several scholars have noted these challenges and the need to involve teachers and students in the development of educational technology (Heikkinen et al., 2022; Viberg et al., 2020; Zawacki-Richter et al., 2019; Zhang & Aslan, 2021).

To address this challenge, the co-design of educational technologies has proven to be a valuable approach (Roschelle & Penuel, 2006; Treasure-Jones & Joynes, 2018; Villatoro Moral & De Benito, 2021). In this context, there has been a call for studies that examine ALT implementation in K-12 classrooms (Gerard et al., 2015). Most studies in this area have been conducted in higher education, where educational technologies are adopted more quickly and there may be fewer restrictions on data access (Johnson et al., 2023; Martin et al., 2020). In this study, we answer this call by focusing on the implementation and development of an ALT through a co-design process that involves both students and teachers in a secondary school. By doing so, we seek to ensure that ALTs are better aligned with pedagogical practices and tailored to individual learning needs, thereby supporting SRL.

3 Co-designing Educational Technology: Empowering Stakeholders for Effective Integration

Innovation in education and learning involves reshaping social practices. Technology can help transform the social dynamics of knowledge creation and reinforce communities of practice (Durall et al., 2019; Hakkarainen, 2009). One way to support the integration of educational technology into teaching is to directly engage various stakeholders such as students, teachers, parents, and principals in a co-design process (Durall Gazulla et al., 2023). Co-design is a valuable approach to democratizing design (Roschelle & Penuel, 2006; Treasure-Jones & Joynes, 2018; Villatoro Moral & De Benito, 2021). Proponents of the approach argue it can be used to address issues that have previously led to failures in technology adoption by recognizing stakeholders' understanding of context, needs, and opportunities (Mor & Winters, 2007). From this perspective, individuals are considered experts in their own experiences. Successful co-design is based on relevant stakeholders' perceptions and experiences (Sanders & Stappers, 2008). It draws from diverse perspectives, relies on different approaches, and involves the collaborative creation of knowledge. Co-design extends to improved implementation of educational technology (Durall et al., 2019; Mor et al., 2015; Villatoro Moral & De Benito, 2021). Penuel and colleagues (2007) describe co-design as a "highly-facilitated, team-based process in which teachers, researchers, and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype's significance for addressing a concrete educational need" (p.51). In other words, co-design in design-based research is a strategy to harness the expertise of pedagogical agents to create, execute, and evaluate educational innovations.

Co-design is particularly successful when the concerns of different interest groups are acknowledged and analyzed. Co-design processes can promote cooperation among stakeholders and strengthen their sense of ownership while enabling more effective and quicker implementation of digital innovations (Durall et al., 2019). Numerous studies have shown the effectiveness of co-design in educational settings. Treasure-Jones and Joynes (2018) asked learners about their challenges and perceptions and actively engaged them in problem-solving. They found that visualizations depicting learning progress offered useful feedback for learners. In another study, students' and teachers' capacity to reflect on their own learning and teaching was improved through the use of mobile apps in a co-design process (Leinonen et al., 2016).

The literature regarding the development and implementation of educational technology in the classroom shows that students and teachers play a central role in co-design (Bovill, 2020; Bovill et al., 2011; Cober et al., 2015). Teachers' perspectives are especially valued as they are seen as the driving force for implementing digital innovations in the classroom (Nicholson et al., 2022). Co-design processes specifically aim to involve teachers, which positively impacts curriculum development and eases the integration of educational technology into practice (Penuel, 2019). It appears, however, that teachers are frequently not sufficiently involved in the development process, impeding effective implementation (Durall et al., 2019; Könings et al., 2014; Lin & Van Brummelen, 2021).

The importance of student perspectives is another key aspect of co-design in this area (Durall et al., 2020; Villatoro Moral & De Benito, 2021). Through effective co-design, students can be given a voice in the development of educational technology and encouraged to actively shape their learning environments. This approach positions learners as protagonists in participatory design, enabling them to influence technological development and critically reflect on the role of technology in their learning practices (Iversen et al., 2017).

Nonetheless, despite the recognized significance of students' perspectives, their views have not been adequately integrated into educational technology design processes. This discrepancy can be problematic, especially when students' perceptions of learning environments diverge from the intentions of teachers or instructional designers (Könings et al., 2014). Learners who are not sufficiently involved in the design process show lower motivation for use (Jahnke et al., 2022) and even a sense of alienation in response to educational technology (Mann, 2001; Treasure-Jones & Joynes, 2018).

4 Research Question

ALTs present a promising method to enhance SRL (Aleven et al., 2017; Bernacki et al., 2011; Faber et al., 2017; Molenaar & Van Campen, 2016; Molenaar et al., 2021; Park et al., 2023; Winne, 2017). To best support SRL through ALTs, it is important to understand learners' needs in their educational context, which can be a challenge for educational science and practice (Azevedo & Feyzi-Behnagh, 2011; Heikkinen et al., 2022; Viberg et al., 2020; Xie et al., 2019; Zawacki-Richter et al., 2019; Zhang & Aslan, 2021).

Co-design is one way to address this challenge by equally considering the perspectives of learners and teachers in the design of ALTs (Könings et al., 2014). Of particular interest is how ALTs can be integrated into school classes (Villatoro Moral & de-Benito Crosseti, 2022), as co-design research has thus far focused on tertiary education (Gerard et al., 2015; Johnson et al., 2023; Martin et al., 2020).

We aim here to address this research gap. In this study, we conduct a co-design process with teachers and students of an upper secondary school with the aim of implementing and developing an ALT that promotes SRL. Based on Durall Gazulla and colleagues' (2023) suggestion, we divide the co-design process into three phases, leading to the following three research questions:

RQ1. What needs can a co-design group identify to develop the adaptive learning technology?
RQ2. What proposed solutions can the co-design group develop?
RQ3. How can the co-design group implement these solutions into a prototype?

5 Method

The goal of this project was to collaborate with students and teachers in the development, testing, and adaptation of a tailored adaptive digital tool. To achieve this objective, we initiated a one-year co-design process in partnership with an upper secondary school (Penuel et al., 2007, 2022). Drawing upon prior studies that applied co-design in education alongside the design and implementation of educational technology to support learning (Durall Gazulla et al., 2023; Mor & Winters, 2007; Penuel et al., 2007; Roschelle & Penuel, 2006), we defined design phases for the current study, as illustrated in Fig. 1.

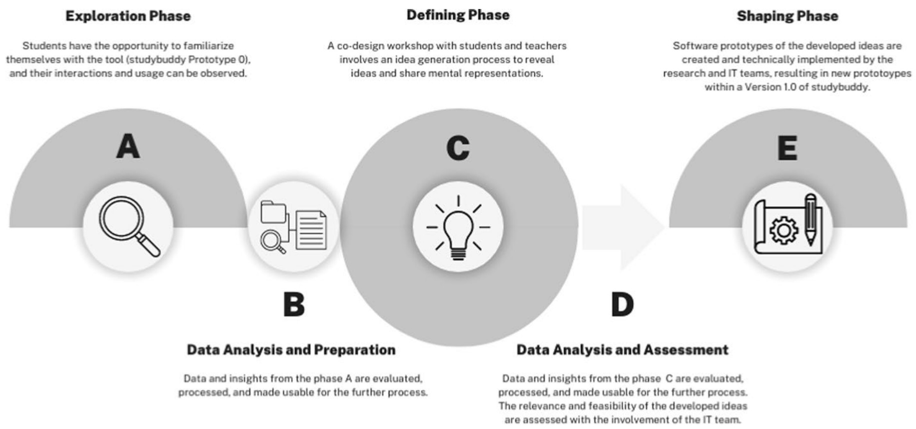

Fig. 1 Research design

As is typical for a co-design process, each phase spanned from a fuzzy phase to a crisp phase (Durall Gazulla et al., 2023). In this study, we defined three main phases: the exploration phase, defining phase, and shaping phase. Between these, we specified intermediate phases in which the data and insights from the preceding main phases were evaluated and made usable for further processing. This approach enabled us to capture the complex relationships between the users of the ALT and their context, thereby eliciting their needs and expectations. Overall, the co-design process involved collecting data from various sources, analyzing the data, and creating prototypes based on the results.

5.1 Participants and Procedure

The co-design project was launched in collaboration with an upper secondary school committed to promoting and supporting SRL. The co-design team developed for this study comprised upper secondary school students and teachers as well as researchers and IT experts from the university. All participants took part in the co-design process voluntarily and were informed in advance by the school principal about its procedure. The co-design team was informed about the study's purpose and all individuals provided consent. The study was approved by the Human Research Ethics Committee of the University of Bern (Ethics approval number: 2022-10-05). Data collection procedures were tested in pilot studies. All data provided by participants were anonymized.

Students from three classes were asked to install and use the digital tool *studybuddy*, previously developed and implemented by the research team for a university context (Prototype 0). Students engaged with the tool in their regular coursework, which included all subjects and tasks relevant to their curriculum. Studybuddy is an ALT in the form of a website and corresponding app that fosters SRL and facilitates a learning environment conducive to SRL (for details, see Mejeh & Rehm, 2024; Mejeh et al., 2024). It consists of four parts: an automated feedback system, a digital dashboard, personalized strategies, and a planning tool.

Based on data-driven insights, the tool provides personalized support in the form of learning strategies. It uses a questionnaire-based approach to collect SRL-relevant data from learners over time, including information on motivation, emotion, cognition, metacognition, and resource management concerning their upcoming tasks. Questionnaires are integrated into studybuddy as daily short surveys administered before, during, and after school. The tool automatically suggests appropriate SRL strategies to learners based on the collected data, if needed.

Students are encouraged to consult the strategy collection as needed, for instance when strategies are not provided on a given day, when the provided strategies are not helpful, or when unforeseen challenges arise during learning. Learners are informed that studybuddy displays information from each completed questionnaire in the app's dashboard, allowing them to easily monitor their progress at any time in areas such as cognitive and metacognitive regulation, emotional and motivational needs, and resource management. Studybuddy can also be used as a planning tool as it features a calendar and note-taking function. For detailed information on the specific functionalities of studybuddy (Prototype 0) and how to use the tool, please refer to the link provided in online Appendix A.

5.2 Co-design Phases

As illustrated in Table 1, each phase of the co-design process pursued a distinct intention, employed different methods, and resulted in different products.

The first main phase (Phase A) was designed to provide insight into the thoughts and actions that learners had while processing feedback from studybuddy version 0. Phase A also provided insights into studybuddy's adaptability, usability, deployment, effectiveness, and ease of use. During this phase, studybuddy was also presented to teachers, who were able to discuss their perceptions of designing SRL-supportive learning environments and the support provided by an ALT such as studybuddy.

In the interim phase (Phase B), the research team analyzed the data collected in Phase A to identify key insights and prepare them for the subsequent development process.

In the second main phase (Phase C), we organized an interactive co-design workshop with students and teachers. Workshop participants were tasked with conducting a SWOT analysis of studybuddy (prototype 0) based on the results from phase A. This analysis was then used to generate ideas for further development, which were documented on Post-It notes and in audio recordings. These ideas were evaluated by the research team in the next interim phase (Phase D), which included assessing the relevance and feasibility of the ideas with the involvement of the IT team. In the third main phase (Phase E), the research and IT teams implemented the ideas, resulting in the creation of studybuddy's new version (prototype 1).

5.3 Measures

During Phase A, we used think-aloud interviews (Leighton, 2017) to gather recollections of thoughts and actions that occurred during the processing of feedback provided by studybuddy. Students were encouraged to articulate any thoughts they had upon receiving this feedback and were presented with a comprehensive overview of the daily feedback course to support remembering (Henderson & Tallman, 2006). Additionally, we conducted semi-structured individual interviews with another group of students to gain further insights into adaptability and user-friendliness (Witzel, 2000). The aim of these interviews was to assess the fit of studybuddy's functions with individual learning and working, alignment of the proposed strategies with individual learning and working, and suggestions for further development of studybuddy's adaptability and personalization.

Table 1 Overview of different co-design phases, methods, participants, and expected outcomes

Phase	Intentions	Methods	Participants	Expected outcomes
A	Familiarization with the tool and observation of the interactions with it	Media-assisted remind aloud interviews	Students (n = 8)	Recollections of thoughts and actions that occurred during the processing of feedback provided by studybuddy
		Semi-structured guided interviews	Students (n = 6)	Insights into the adaptability and user-friendliness of studybuddy
		Group discussion A	Students (n = 3)	Information on the use, effectiveness, and usability of studybuddy, along with suggestions for further development
		Group discussion B	Teachers (n = 4)	Insights into the perceived relevance of SRL promotion at the school, support needs for designing SRL-supportive learning environments and the potential of SRL promotion through studybuddy
B	Data analysis and preparation for the next steps in the Co-design process	Qualitative data analysis: thematic analysis	Research team	Overview of the data available to participants in the co-design workshop for further work
C	Co-design workshop to generate ideas and share mental representations	SWOT-Analysis Idea generation using Post-Its and audio recordings	Co-design team build of students (n = 5), teachers (n = 2), researchers (n = 3) and IT specialists (n = 2)	Possibilities and challenges related to the further development of studybuddy
D	Data analysis and preparation for the next steps in the Co-design process, including the assessment of the relevance and feasibility of the developed ideas	Qualitative data analysis: thematic analysis	Research team	Final analysis of the co-design data and an overview for the research and IT team to use in the prototyping process
E	Prototyping of the developed ideas and technical implementation	Prototyping	Research team IT team	Prototype of studybuddy version 1

We held two group discussions, one with students and one with teachers, to capture more detailed insights into the need for and feasibility of SRL support through studybuddy at the upper secondary school (Onwuegbuzie et al., 2009). In the student discussion, we gathered information on the use, effectiveness, and usability of studybuddy, and suggestions for further development. In the teacher group discussion, we aimed to identify support needs for designing SRL-promoting learning environments and assess the potential of SRL promotion through studybuddy. The interview guides for all interviews can be found in online Appendix B.

In Phase C, students, teachers, and researchers conducted a SWOT analysis as part of the co-design workshop, building upon the results from Phase B (McKercher, 2020). The objective was to identify the strengths, weaknesses, opportunities, and challenges of the tool. This facilitated a comprehensive evaluation of the collected data by the co-design group and served as a starting point for the idea-generation process. The proposed ideas for further development of studybuddy were documented on Post-It notes, as this sketching technique aids in idea revelation and facilitates the sharing of mental representations (McKenney et al., 2015).

5.4 Data Analysis

We conducted a thematic analysis of qualitative data gathered in Phase A to identify, analyze, and report patterns within the data. We followed recommendations from Braun and Clarke (2006), who propose six phases for thematic analysis: familiarizing with the data, generating codes, searching for sub-themes, reviewing sub-themes, defining, and naming main themes, and producing the research report. As such, once both researchers became familiar with the data, codes were inductively generated and the data were organized into sub-themes. These sub-themes were reviewed, defined, and used to craft the main theme. Each sentence unit was coded per occurrence of a condition. Interpretations, evaluative statements, and understanding of content were included in the analysis. A text segment could be assigned to a code more than once. We used the MAXQDA software for coding. Audio material was transcribed verbatim with minor language editing (Kuckartz & Rädiker, 2019). Table 2 provides an overview of initial codes and corresponding sub-themes regarding the main theme. To ensure intersubjective comprehensibility, the authors conducted and discussed the coding of two interviews together. Inter-rater reliability for the two interviews was good, with a kappa value of .82 (McDonald et al., 2019).

6 Results

The main theme that emerged from our thematic analysis was the adaptivity of the digital tool. There were four subthemes: adaptation to school lessons and curriculum, adaptation to individual learning and working behavior, adaptation to learners' emotional and motivational needs, and adaptation to individual daily routines (see Fig. 2). We present the study results below, organized by the exploration, defining, and shaping phases.

6.1 Adaptivity

The results revealed a diversity of experiences and needs in the individual use of studybuddy. Learning preferences, personal schedules, and acceptance of the support provided

Table 2 Overview of initial codes, sub-themes, and main themes

Initial codes	Sub themes	Main theme
Fit between the support provided by studybuddy and the learning object/tasks	(a) Adaption to school lessons and curriculum	Adaptivity
Fit between the support provided by studybuddy and the timetable		
Direct integration of studybuddy into the lessons		
Fit between the support provided by studybuddy and the individual learning and working rhythm	(b) Adaption to one's learning and working behavior	
Fit between the support provided by studybuddy and the individual learning style		
Fit between the support provided by studybuddy and the individual's prior knowledge/individual skills in relation to SRL		
Fit between the support provided by studybuddy and the changes/progress made in terms of learning behavior		
Self-assessment in relation to SRL skills		
Perceived relevance of the support provided by studybuddy	(c) Adaptation to individual emotional and motivational needs	
Willingness to adapt own learning behavior		
Fit between the support provided by studybuddy and individual extracurricular activities (hobbies, appointments, etc.)	(d) Adaptation to individual daily routine	
Fit between the support provided by studybuddy and the individual daily routine (sleep rhythm, etc.)		

Fig. 2 Subthemes of adaptivity derived from the data across co-design phases A to C

by the digital tool varied among participants. These diverse perspectives indicate a need to tailor ALTs to users' specific challenges. We thus suggest that flexibility around the deployment and content of ALTs is a central concern for students and teachers and that this flexibility is key for the support to be effective. Table 3 summarizes results concerning adaptivity from the three phases for each sub-theme.

6.1.1 Adaptation to School Lessons and Curriculum

Studybuddy's alignment with the curriculum and class schedule emerged as an important component for the tool's effective use. One observation was that push notifications were frequently disregarded when delivered to learners at inappropriate times. This could be attributed to misalignment between studybuddy's predefined system schedule and students' individual timetables. For instance, students with later classes required support during those times rather than early in the morning. There was a clear preference for push notifications before and after school, with support during school often perceived as disruptive:

> I find this post-notification the easiest to assess as it occurs after school, allowing for better reference to the school day compared to, for example, before or during school. (student_individual interview_7)[1]

Moreover, the predefined learning content and tasks embedded in existing school structures and the curriculum posed obstacles to the optimal use of ALT designed to support SRL in students. This perspective was shared by teachers who found limited opportunities to establish a supportive SRL environment within these structures. They noted that

[1] Interview statements are labeled by person_interview form_number of person.

Table 3 Synthesis of results of main co-design phases

	Exploration phase What needs can be identified?	Defining phase What solutions were developed?	Shaping phase How were the solutions implemented?
School lessons and curriculum	Aligning studybuddy's system schedule with individual student timetables	Integration of personal timetables	Individual setting of deadlines
		Optimal utilization of studybuddy's app and web versions	Interactive tutorial
	Aligning studybuddy to tasks and the current curriculum	Integration of a to-do list	To-do-list
Learning and working behavior	Enhancing flexibility in support aligned with students' learning and working processes	Implementation of an Emergency Support Button	Emergency support button
		Scheduling individual learning phases	To-do list Individual setting of timers
	Enhancing targeted support for experienced learners with suggested strategies or advanced SRL skills	Including a broader range of questions into the questionnaire	NLP Algorithms
		Opportunity for students to evaluate the proposed strategies	Thumbs up thumbs down function
Emotional and motivational needs	Assisting students in self-assessing their SRL skills	Introducing studybuddy early in the school year for testing	
		Promoting voluntary participation in using studybuddy	
			Self-assessment test for SRL skills
	Increasing the significance of suggested strategies for students	Developing a motivational introduction to studybuddy	Interactive tutorial
Extracurricular activities	Monitoring and integrating extracurricular activities and associated workload for enhanced support	Personalization reminders through the ALT	To-do list Individual setting of deadlines

SRL skills were in higher demand in more open teaching structures and could be better cultivated than in traditional instruction, such as frontal teaching. This point highlights the central role of instructional design in effectively regulating learning, even when using ALT. Teachers recognized that a tool could adaptively promote students' SRL and critically reflected on better integrating it into their existing instruction:

> I could imagine that I could at least get better at making the topic 'what helps me learn' more visible to students. (teacher_group discussion_3)[2]

During the co-design workshop (Phase C), participants proposed solutions for improving the integration of studybuddy with individual schedules and overcoming temporal constraints. Regarding alignment with the school curriculum, one highlighted challenge was effectively using ALT support for existing learning content or ongoing tasks. To improve alignment between learning content and ALT support, the co-design group proposed implementing a to-do list that would enable students to input upcoming tasks, allowing the system to offer more specific temporal and content-related support. It was also proposed that personal timetables should be integrated into the tool to ensure support was tailored to individual schedules. To address issues related to push notifications causing distractions during class, participants recommended shifting interactions with the ALT towards laptops and reducing reliance on mobile phones. The co-design group identified mobile phones as a potential source of disturbance and distraction, while laptops were perceived as work tools that were less conducive to potential distractions.

In Phase E, the research team collaborated with the IT team to integrate the proposed ideas and further develop the ALT. A to-do list function was introduced which would provide students with the capability to input, label, and elaborate on their upcoming tasks and learning objectives. Additionally, students would now have the flexibility to set deadlines and specify preferred reminder times. The primary aim of this feature was to enhance the synchronization of push notifications with individual learning and working rhythms. The research team opted for this approach instead of a predefined schedule, meaning all standard push notifications were replaced by timed notifications that learners set themselves. Additionally, an interactive tutorial was developed to guide users through the tool's functions, ensuring optimal use.

6.1.2 Adaptation to Individual Learning and Working Behavior

Students identified that alignment between their individual learning and working rhythms and support from the ALT was another important factor. They expressed a need for greater flexibility and the freedom to decide when to leverage support, aligning it with the timing of their learning and working processes. Also on the topic of timing, teachers expressed that students were particularly receptive to assistance and new approaches in specific phases of the learning process. They reported it was common that the same support was not equally effective for all students, as they could be in different work and learning phases. Teachers believed this principle also applied to the support provided by an ALT. In addition to appropriate timing, teachers noted that proper dosage (how often and how intensely support was provided) impacted the effectiveness of the assistance and that it should not be assumed that every student needed the same level of support. While one student may

[2] Group discussion statements are labeled by person_interview form_number of person.

require support three times a day and be unfamiliar with basic learning strategies, others may need less support and assistance could occur at a different cognitive level.

> I believe there could be straightforward steps for individualization, such as having the ability to control the times oneself. (teacher_group discussion_1)

In this context, different needs regarding the quantity and quality of support were attributed to the continuous development of SRL skills. Each student's learning strategies evolve throughout their school career, and teachers assume that many strategies should already be developed in higher grade levels. Consequently, some learners criticized the support provided by the ALT as they were already familiar with suggested strategies or needed less assistance due to already having well-developed SRL skills. In these cases, learners often preferred their own strategies over the newly suggested ones.

> I just looked to see which strategies were there, and then I realized that I already knew them, so I didn't really need to review them again. (student_think aloud interview_2)

To address these issues, students recommended that studybuddy should take into account the progress and changes already achieved in their learning behavior. They proposed that the system should inquire more precisely about their individual needs and provide multiple learning strategy options. Furthermore, the ALT should be capable of capturing their preferences regarding learning styles, recognizing that some students prefer group learning, oral learning, or analog methods.

At the co-design workshop, two approaches were discussed to enhance synchronization between learning and working rhythms and support from the ALT. One suggested approach was to implement an "emergency support button" that would allow students to receive direct and immediate support from studybuddy when pressed. Another suggestion involved weekly input of individual learning periods, which would enable support activation exclusively within the times specified by students. To address the variation in starting levels of students' SRL skills, the co-design group proposed incorporating more diverse and specific questions into the questionnaire. The data collected from these questions could be used to establish a learning profile that took students' initial levels into account and tracked progress for future support suggestions. Additionally, the group proposed an option for students to evaluate suggested learning strategies, providing a means for them to assess the alignment of these strategies with their needs.

In addition to implementing the to-do list and the option of scheduling individual learning phases, collaborative efforts between the research and IT teams during Phase E led to the creation of an emergency support button feature. This feature was designed to offer real-time support for students in situations where they required immediate assistance. By activating the button, students could initiate a request for help. Subsequently, a push notification would appear, asking students to fill out a survey, after which tailored strategies would be suggested. Natural language processing algorithms were incorporated into the tool to enhance the analysis of student data for a more precise diagnosis of their needs and to provide tailored feedback. Learners now had the flexibility to input information to communicate their needs, either through free text or voice messages, which were converted using a speech-to-text program. Furthermore, following the suggestion of an SRL strategy, students had the option to provide feedback using a "thumbs up/thumbs down" function, indicating whether the recommended strategy was helpful for them or not.

6.1.3 Adaptation to Individual Emotional and Motivational Needs

While analyzing teacher statements, an inconsistency became apparent in the personal significance students attributed to the support provided by studybuddy. This was closely linked to learners' willingness to adjust their learning behavior. One factor influencing this dynamic was students' self-assessment of their abilities in SRL, which was perceived by teachers as a prerequisite for receiving support. Recognizing this, studybuddy should assist students with the initial self-assessment of their abilities.

The willingness to implement support is linked to the importance students place on respective support strategies. Teachers stated that for effective support, students needed to acknowledge and understand their own learning capabilities. Thus, a cohesive approach involves studybuddy fostering self-assessment and aligning this with the perceived significance of the support strategies. Teachers identified that some students who believed they did not require support might actually benefit from it, while students who actively sought assistance may not necessarily need it. Hence, students' openness to support could be influenced by a potentially inaccurate self-assessment and by willingness to accept support, based on their motivational and emotional states. The analyses of students' interview data depicted ambivalence around receiving support, showing that learners' motivational and emotional states could influence studybuddy's adaptive function. The feedback from the system was perceived at times as negative and stressful (e.g., in situations of time pressure) and at other times as supportive (e.g., before exams or in anxiety-inducing situations).

> After a while, I lose the motivation to put in as much effort. Perhaps it's due to the recent busy weeks, leaving me with little time to make changes in my learning approach. (student_individual interview_2)
> I think especially in highly stressful situations, for me at least, when I experience a lot of stress, I tend to postpone many things, including learning. (student_individual interview_1)

To foster a greater willingness to use studybuddy, participants in the co-design workshop suggested introducing the tool early in the school year and making it available for testing. This approach would allow students to experiment with the tool and determine how and when the system could best support them to gradually establish a routine for use. As an additional measure, participants noted a need for a motivational introduction to the tool. Understanding the benefits and potential applications would help students overcome skepticism and boost motivation for use. Participants proposed organizing test workshops in which students could familiarize themselves with the tool. The co-design group suggested that voluntary participation in using the tool was key, as this approach enhances self-initiative and motivation, ensuring students engage with the tool willingly.

In addition to optimizing the tool, the interactive tutorial developed during the shaping phase served the purpose of systematically guiding users through the software's functions, with the aim of enhancing motivation to use it. Learners could also now answer questions designed to evaluate their SRL skills, with outcomes displayed on the dashboard. The aim of this feature was to enhance students' knowledge of their own SRL skills.

6.1.4 Adaptation to Extracurricular Activities

Teachers described the use of studybuddy as phase-dependent, meaning that students' frequency of ALT use depended on their current life conditions. Teachers reported that during periods when students faced personal challenges such as family, interpersonal, or sporting issues, they tended to prioritize personal situations and focus less on learning. This observation was validated by students, who acknowledged using ALT less frequently when facing time constraints due to extracurricular activities such as hobbies, appointments, or events. To manage these activities, students had to navigate daily routines including mealtimes, sleep schedules, and extended school commutes. The efficacy of the tool relied on its alignment with these daily routines. In response to this feedback, there was a demand for studybuddy to accommodate diverse extracurricular circumstances.

Addressing the challenge of identifying and capturing extracurricular circumstances, the co-design group proposed that students should have the ability to personalize reminders in the ALT based on their individual situations. However, if the system detected a prolonged lack of reactivity or no interaction, it should send a general reminder to encourage users to re-engage with the system. Around the to-do list created in the shaping phase, students could also independently set the timing and frequency of reminders for their extracurricular activities, such as sports. This level of flexibility allowed them to seamlessly synchronize reminders with their learning goals, eliminating the need for generic push notifications.

7 Discussion

In this study, we investigated how a co-design process could be used to develop and implement an ALT to support the SRL of secondary school students. This involved three main phases: *exploring* identified needs for the technology's development, *defining* potential solutions, and *shaping* these solutions into a next prototype.

7.1 Addressing Feasibility Challenges in ALT Integration

In the exploration phase of the study, we examined the needs expressed by students and teachers about the use of an ALT. Our findings showed that the application of studybuddy spanned a range of domains that encompassed school and classroom structures, learning behaviors, affective learning prerequisites, and extracurricular activities. This highlights that the effective use and integration of ALT depends on factors pertaining to individuals, schools, and the wider education system (Petko, 2012). However, our results also indicated that significant feasibility challenges would arise if scaling an ALT systematically linked to specific tasks or even the curriculum. This is due to substantial differences among school curricula in promoting SRL, with even greater variability expected in individual tasks assigned in lessons (Alvi & Gillies, 2020).

Against this backdrop, directly linking the tool to the existing curriculum or individual student tasks would require teachers to more actively incorporate educational technologies into lessons. Teachers would be required to make tasks accessible to students through the digital tool. However, in the context of technology acceptance and integration in schools (Davis, 1989; Knezek & Christensen, 2016; Mishra & Koehler, 2006), research suggests that the introduction of uniform educational technologies can result in resistance from teachers (Michos et al., 2023; Sánchez-Prieto et al., 2019; Schmid et al., 2022), posing a barrier to the integration of educational technologies in the classroom (Schmitz et al., 2022).

The co-design process was effective in overcoming this challenge (Durall Gazulla et al., 2023; Roschelle & Penuel, 2006; Treasure-Jones & Joynes, 2018). Our findings showed that the involvement of a co-design group revealed the limitations of the initial version of studybuddy (prototype 0), developed solely by the researchers. The challenges that emerged during the exploration phase laid the foundation for collaborative solutions in the defining phase. The collaborative development of a to-do list, personalized timetables, and tailored prompts, enhanced the adaptability of studybuddy and addressed issues linked to school and classroom structures.

The utility of incorporating the perspectives of students and teachers into the design process (Bovill, 2020; Cober et al., 2015; Könings et al., 2014) became especially apparent when their perceptions and descriptions aligned. Both groups recognized the importance of prompt support from the ALT, albeit with different rationales. Students noted the relevance of direct support, advocating for timely, personalized, and task-specific SRL strategies. Teachers acknowledged the potential benefits of an ALT such as studybuddy but also highlighted the impediments posed by existing school and classroom structures, making indirect activation of SRL challenging. Previous studies on the effective promotion of SRL have consistently shown the importance of combining direct support for SRL with indirect activation of SRL (Dignath & Veenman, 2021; Perry et al., 2020).

7.2 Translating Co-design Inputs into Practical ALT Features

In the shaping phase, the majority of the co-design group's suggestions were incorporated into studybuddy by the IT experts and successfully implemented. This generally confirmed the assumption that co-design processes lead to a faster and more efficient implementation of digital innovations (Durall et al., 2019). That said, not all suggestions from the co-design group resulted in further ALT development. For instance, we faced challenges in implementing the suggestions of introducing studybuddy at the beginning of the school year and promoting voluntary participation through features embedded in the ALT. Thus, the shaping phase illuminated potential restrictions affecting educational technology and how tools must consistently be integrated into educational practices (Costa et al., 2021; Könings et al., 2014; Penuel, 2019).

Conversely, the self-assessment test for SRL skills was employed during the shaping phase to further develop studybuddy. This was a challenge for which no solution had been found during the co-design workshops in the defining phase, demonstrating that co-design processes are inherently messy and the boundaries between phases cannot always be clearly separated—they sometimes even interact (Durall Gazulla et al., 2023). While this study addressed the research gap to link the development and implementation of ALT to pedagogical practice through co-design and created conditions for successful implementation and impact (Heikkinen et al., 2022; Zawacki-Richter et al., 2019; Zhang & Aslan, 2021), it also highlights the challenges of such an approach. Another such challenge was translating content between the groups involved (students, teachers, researchers, and IT experts). For instance, some of the co-design group's ideas from the definition phase were not technically feasible and thus could not be implemented. In some instances, the IT experts' suggestions for integrating new functions were insufficient for the researchers. For example, the initial implementation of the to-do list was deemed inadequate by the research team as it lacked sufficient linkage to the tool's underlying model (COPES, Winne & Hadwin, 1998). Similar challenges have been described in other studies on educational technology integration through participatory development and should be considered before embarking on any co-design project (Kujala, 2003; Mor & Winters, 2007).

The co-design in our study enabled us to generate novel findings regarding the adaptive promotion of SRL through an ALT. In the exploration phase, for example, it became apparent that the diagnostic and support function of studybuddy needed further development to increase adaptivity to learning and working behavior and learners' emotional and motivational states. Adding features such as an emergency support button, individual timer settings, natural language process algorithms, and an evaluation function for proposed SRL strategies gave learners more control over their learning, which is a key feature for the successful promotion of SRL (De Naeghel et al., 2016; Perry, 2013; Perry et al., 2020; Reeve, 2006). Our results complement earlier findings and affirm that a desire for autonomy among learners extends to using ALT.

The importance of adaptive feedback was also shown as important for the learning process (Butler & Winne, 1995; Mejeh et al., 2024; Theobald & Bellhäuser, 2022; Theobald et al., 2023). This is best illustrated using the example of prompted strategies, where we identified a disparity between intended and perceived support from the ALT (Sedrakyan et al., 2020). One explanation for this difference is that SRL can be understood both as a temporally stable personality trait and as a context-dependent, task-related behavior of learners (Matthews et al., 2000; Winne & Perry, 2000). The phases of the co-design process highlighted the challenge of developing an ALT that could support SRL while being task-unspecific. This difficulty arose either due to the challenge of transferring strategies from general to specific examples or because strategies were formulated too specifically to be applied to different situations. Therefore, our initial goal for studybuddy to solely support the generic SRL of learners needed to be adjusted. This involved incorporating a task-specific function and allowing learners to define their upcoming tasks, specify deadlines for completion, and indicate whether they required support in accomplishing these tasks.

8 Implications and Limitations

The aim of the present study was the implementation and further development of an ALT to enhance learners' SRL through a co-design process conducted over multiple iterations. Regarding theoretical implications, our study can be seen as a first step towards integrating ALT into a co-design process in upper secondary schools (Gerard et al., 2015). Co-design research into educational technology has so far focused almost exclusively on higher education (Johnson et al., 2023; Martin et al., 2020). Practically, our study highlights the importance of involving affected stakeholder groups (Könings et al., 2014), while methodologically, we demonstrated how co-design can contribute to the improved development and implementation of ALT (Durall et al., 2019; Durall Gazulla et al., 2023).

Our study had several limitations. First, the co-design process was conducted with one school, precluding generalization. As the aim of single case studies is not to make universally valid statements (Yin, 2018), expanding collaboration with multiple schools in the future would help gather more information about the use, development, and effectiveness of studybuddy. For instance, stakeholders could participate in the tool's development through a light co-design approach during a broader implementation phase (Treasure-Jones & Joynes, 2018). Nevertheless, this limitation affects the external validity of our findings, as the specific context and characteristics of the school may have influenced the results. Future research should aim to replicate the study in diverse educational settings to enhance the generalizability of the findings. Moreover, the adaptive promotion of SRL through an ALT posed challenges in balancing general and task-specific support (Matthews et al., 2000; Winne & Perry, 2000). This shift showed the difficulty of developing an ALT that was both adaptive and specific to different learning contexts. Future studies could investigate strategies to enhance the adaptivity of ALTs while maintaining their relevance across diverse educational scenarios.

Second, despite involving teachers in the co-design process, we did not refer to teachers' classroom practices regarding the integration of educational technology. While educational technology can help to enhance understanding of SRL (Winne, 2022), it is equally important to consider how researchers can support teachers in incorporating educational technology into their instructional practices (Nicholson et al., 2022). Our lack of focus on integration strategies may have led to an underestimation of the challenges teachers face and the support they needed. Future studies should examine the relationship between lesson planning and teachers' use of educational technologies in more detail to inform practical implications for teacher education and training (Moltudal et al., 2022; Ng et al., 2024).

A third issue was the practical constraints we faced in implementing the ALT. In particular, challenges were encountered in introducing studybuddy at the beginning of the school year and promoting voluntary participation. These constraints highlighted the limitations of integrating educational technology into ongoing school and teaching activities. Addressing these issues requires long-term research-practice partnerships to implement, test, and refine ALT (Ng & Fergusson, 2019).

Finally, there were problems with translation among the groups of stakeholders involved during the co-design process. While numerous ideas generated by the co-design group were integrated into the further development of studybuddy (prototype 1), some suggestions were not. The complexity of communication and translation among diverse stakeholder groups may have led to misunderstandings or incomplete implementations of co-design inputs. We recommend that researchers carefully distinguish between minor and major changes resulting from the ALT co-design process, transparently discussing the extent of modifications with other participating groups. To achieve this, future projects should incorporate structured communication protocols and feedback loops to ensure the effective translation of generated ideas into practice. This approach can increase the likelihood of further cooperation (Durall et al., 2023).

9 Conclusion

This study aimed to develop and implement an ALT to enhance SRL among upper secondary school students through a co-design process. By involving students and teachers, we identified key needs and challenges in integrating ALT in the classroom. The co-design approach was effective in addressing initial limitations and enabled the development of features such as personalized timetables and tailored prompts. The study highlights the importance of considering direct and indirect support for SRL, showing that an ALT can significantly impact learning behaviors when effectively linked to teaching practices. While generalizability is limited by this being a single case study, the findings provide a valuable first step towards broader implementation and offer insights into the complex dynamics of co-design. Future research should expand on these findings by involving multiple schools and focusing on the practical integration of educational technology in classroom practices. Addressing the identified limitations will further enhance the adaptability and effectiveness of ALTs, contributing to improved educational outcomes.

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Declarations

Conflict of interest There is no relevant financial or non-financial competing interests to report.

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