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Enhancing Student Engagement in Civil Engineering Education Through Innovative Self-Regulation Practices in Remote Laboratories: A Systematic Literature Review

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Abstract

The proliferation of technology and the shift towards remote learning have significantly transformed the landscape of engineering education. This evolution has been driven by various factors, including changing student demographics, rapid technological advancements, and global disruptions such as the COVID-19 pandemic. Considering these developments, this systematic review synthesises evidence regarding the application of innovative self-regulation strategies that are facilitated by technology-enhanced remote learning environments. The focus was on enhancing student engagement, specifically within virtual laboratories in engineering education. To conduct this review, a meticulous systematic search was performed across prominent electronic databases, including IEEE Xplore, ERIC, and Web of Science. The findings highlight that integrating self-regulation practices with cutting-edge technologies such as artificial intelligence (AI), virtual reality (VR), and machine learning has a positive impact on student engagement and participation rates. Moreover, it correlates with improved learning satisfaction in remote environments. High levels of student engagement are manifested through effective time management strategies, consistent interaction with learning content, and sustained motivation throughout the learning process. However, the review also identified persistent challenges that educators and students face in a remote learning context. These challenges include feelings of social isolation and disconnection among students, inequalities regarding access to essential technology, and a general lack of preparedness among faculty in terms of the necessary infrastructure and resources for effective online teaching. This review offers valuable insights into how technology-enhanced self-regulation practices can boost engagement in remote engineering education, informing strategies to improve student experiences in virtual settings.

Keywords: Engagement; Laboratory; Learning; Remote engineering education, Self-regulation; Technology

Introduction

Engineering education is undergoing major transformation owing to changes in student demographics, technological innovations, and international events. For example, the COVID-19 pandemic forced educators to adopt remote learning modalities unlike anything ever seen before (García-Ramírez, 2025). Civil engineering education faces challenges in integrating these new learning modalities while preserving the traditional strengths of practical skill development through hands-on laboratory work and field training (Faza & Lestari, 2025). Research on integrating innovative self-regulated practices into remote laboratory learning has gained momentum, focusing on improving learners' engagement and learning outcomes in an evolving educational landscape.

Self-regulated learning has received significant attention in technology-based remote learning contexts. Self-regulated learning involves actively monitoring, controlling, and regulating students' behaviour and cognition to achieve educational goals (Li & Liang, 2024). In the current learning environment, where remote learning supplements or replaces traditional instruction, civil engineering students must adapt to self-regulation practices to acquire essential theoretical and technical skills (Escobar-Castillejos et al., 2025). Student engagement research supports these views, indicating that self-regulation behaviours determine student engagement levels. One study found that many students maintain high assignment submission rates, demonstrating their ability to self-regulate in remote learning environments (Hadwin et al., 2011)

Design and implementation innovations in remote laboratories have a considerable influence on student learning outcomes, engagement, and motivation (Matarneh et al., 2025). Evidence in the literature connects innovative solutions like virtual reality, augmented simulations, collaborative online environments, AI-based learning models, and gamification strategies with enhancing peer learning and social interaction (Saldívar-Almorejo et al.,2024) Current studies examining patterns of student engagement indicate that about 7% of students actively contribute to forum discussions, highlighting the need to adopt strategies that promote collaborative learning in remote setups (Hadwin et al., 2011).

The notion of student engagement is complex, covering learners' behavioural, cognitive, and affective dimensions that affect their learning outcomes (Al-Khatib et al., 2024). The behavioural dimension involves active participation in classroom activities, such as attending, submitting assignments, and interacting with others and with lecturers. The cognitive dimension refers to the psychological and strategic orientations that learners adopt in learning activities, such as deep learning and self-regulation strategies. The emotional element describes learners' motivation and interests towards learning tasks and educational activities (Farrokhnia et al., 2025). Extensive evidence demonstrates strong relationships between multiple engagement indicators ($r>0.6$), highlighting the multifaceted nature of student engagement in remote learning (Hadwin et al., 2011).

This systematic review examines existing research on integrating innovative self-regulation practices in remote laboratories to enhance student engagement in civil engineering education. The review addresses several research questions: Does integrating innovative self-regulation learning activities strengthen student engagement in remote laboratories? What technological and pedagogical innovations are most effective in improving student engagement in distance learning? What are the challenges to implementing these innovations, and how can they be addressed? What are the implications for the future of civil engineering research and practice?

Methodology

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) standards.

Search Strategy

A comprehensive search strategy was developed to retrieve relevant literature for synthesis. The authors searched databases, including IEEE Xplore, ERIC, and Web of Science, to locate studies on innovative self-regulation practices integrated into remote laboratories to enhance student engagement in civil engineering education. Additional studies were identified by examining the reference lists of eligible studies and searching for these on Google Scholar. Various keywords were developed to aid in the search, and Boolean operators were used to expand the search and generate adequate records for synthesis. The keywords included: ("remote laboratories" OR "virtual laboratories" OR "online laboratories" OR "self-regulation learning" OR "digital learning environment") AND ("student engagement" OR "learner engagement" OR "academic engagement" OR "motivation" OR "participation") AND ("civil engineering education" OR "engineering education" OR "STEM education").

Inclusion and Exclusion Criteria

This review included peer-reviewed journal articles and conference proceedings that examined the integration of self-regulated practices in remote or virtual laboratories to enhance student engagement in civil engineering education. Studies published in English between 2020 and 2025 were included in the review. Furthermore, studies that did not focus on self-regulated approaches integrated into remote laboratories to enhance student engagement in civil engineering education were excluded. In addition, studies lacking substantial empirical content, including those with incomplete results, were also excluded. The review also excluded studies or conference proceedings published in languages other than English or published before 2020.

Study Selection and Quality Assessment

The process of selecting eligible studies included multiple screening stages. The preliminary screening involved reviewing titles and abstracts to exclude studies not focused on self-regulated practices, remote or virtual labs, or student engagement in civil engineering education. The complete content and texts of the remaining studies were reviewed, and studies that failed to satisfy the inclusion criteria outlined above were excluded. Key information, such as study authors, aims, participants, study design, and primary findings, was extracted from eligible studies.

Quality assessment was performed using the Cochrane Risk of Bias tool for randomised controlled trials. The Critical Appraisal Skills Programme (CASP) checklist was used to assess the quality of qualitative and mixed methods studies. Studies were rated as low, moderate, or high quality depending on their methodological rigour and clarity of findings.

Data Synthesis

Narrative and thematic approaches were used to synthesise the extracted data. Thematic analysis was employed to identify emerging patterns and themes from the synthesised literature. These themes were described to create insights into how technology-enhanced self-regulation practices influence student engagement in civil engineering education.

Literature Review

Innovative Self-Regulation Practices in Engineering Education

Innovative self-regulation practices have emerged as effective strategies to enhance student engagement and improve learning outcomes in remote learning environments. García-Ramírez (2025) investigated the application of STEM-based prototyping activities in civil engineering education (García-Ramírez,2025). Their findings suggest that activities incorporating hands-on, project-based approaches during learning activities foster self-directed and problem-solving skills in students and improve their engagement levels.

Studies have attempted to establish links between self-regulation practices and students' distinct behavioural patterns. Research assessing the integration of quiz review behaviour reports that students with high engagement averaged 2.1 quiz reviews compared to 1.8 quiz reviews among low engagement students before submission (Hadwin et al., 2011). Learning environments that utilise forum participation have reported that, although active participation in discussions is limited, overall engagement across different metrics tends to be higher among participating students (Chen et al., 2018).

Faza and Lestari (2025) systematically reviewed self-regulated learning strategies in the technology age. The review indicated that students who set goals and track their progress showed more persistence, satisfaction, and better academic grades. The study highlighted the importance of explicit instruction and the integration of technology in self-regulation approaches to enhance learning outcomes.

Biwer et al. (2025) employed qualitative techniques to examine self-regulation practices of undergraduate engineering students in learning environments. The research aimed to gain insight into the cognitive and behavioural strategies adopted by students during learning. The research established elaboration, organisation, planning, monitoring, management, and help-seeking as the most prevalent self-regulation strategies among students. Contextual factors were found to shape how these strategies were employed, emphasising the need for interventions that foster self-regulation skills.

The temporal aspect of self-regulation practice is evident in classroom participation activities such as assignment submission patterns. Literature evidence from analysis of self-regulation practices reveals that high-engagement students demonstrate greater assignment completion rates across subjects, suggesting superior adaptation and time management skills (Hadwin et al., 2011). This evidence indicates that self-regulation approaches can be refined and tailored to students' unique needs, increasing their autonomy and accountability in learning and leading to enhanced learning experiences.

Technology-enhanced learning environments and student engagement

New opportunities have emerged with technology integration in engineering education. Technology facilitates effective student engagement and enables immersive, interactive, and personalised learning experiences. Li and Liang (2024) conducted a meta-analysis to provide insights into the influence of online laboratories on student outcomes in engineering education. Their study reported that online laboratories had significantly positive effects on student outcomes (pooled effect size = 0.686). Students also demonstrated greater problem-solving skills, conceptual understanding, and motivation.

Virtual reality (VR) and augmented reality (AR) have shown promise in enhancing student engagement in civil engineering. Students utilise these technologies for remote collaboration and design visualisation in engineering education. Suhail et al. (2024) conducted a systematic review of AR applications in engineering education, predominantly addressing how they can improve students' conceptual understanding, enhance engagement, and increase motivation in remote learning. The review found that integrating AR with hands-on and collaborative learning activities achieved superior outcomes compared to implementing AR alone as a technological intervention.

A significant amount of research has demonstrated strong correlations between technology-enhanced learning activities and traditional performance indicators. One study showed that higher technological engagement, assessed through login frequency, platform usage, and content interaction, was strongly correlated with performance measured using traditional metrics (Hadwin et al., 2011). Escobar-Castillejos et al. (2025) evaluated the design and implementation of digital learning systems to facilitate student and tutor engagement across various learning modalities, while supporting the unique needs of individual students. The findings indicated that implementing well-designed digital learning platforms offers opportunities for personalised and collaborative learning. It also provides efficient feedback mechanisms that enhance students' engagement levels. The study recommended user-centred designs combined with continuous evaluation and refinement for optimal outcomes.

Analysis of learning progress effectively identifies distinct patterns in students' adoption of digital learning platforms in engineering education. Evidence from literature shows a decrease in assignment completion times from 150 hours to 95 hours among high-engagement students. Technology-supported learning activities accentuate disparities in student self-regulation skills, indicating the necessity for personalised supportive interventions. Mena-Guacas et al. (2025) presented a systematic review of the advantages and prospects of implementing technologies like VR, AI, and adaptive learning systems. The review reported that combining these technologies with pedagogical models improves student engagement, collaboration, and evaluation. The review suggests that learning institutions must support and develop instructors in implementing and embracing AI technologies in learning activities.

Artificial Intelligence and Personalised Learning Approaches

Artificial Intelligence (AI) can directly support students' self-regulation in remote engineering laboratories. AI offers practical mechanisms for supporting modelling, monitoring and feedback tailored to the students' regulatory needs. Through intelligent tutoring, adaptive assessment and learning analytics, AI allows students to plan, set specific goals, manage time, and monitor and reflect on their learning performance (Mena-Guacas et al., 2025). Research has shown that AI tutoring systems personalise the difficulty and sequencing of tasks to match students' current skill levels. This allows students to set realistic goals, preventing them from disengaging owing to task difficulty. Machine-learning models can detect time-management problems and low login or interaction frequencies, and thus predict student disengagement and trigger targeted interventions such as reminders (Suhail et al., 2024; Merino-Campos, 2025).

Past research shows a positive relationship between AI implementation and student engagement. Studies focusing on data-driven systems have shown reduced disengagement and improvements in students' learning and feedback. Abouelenein et al. (2025) report that learning analytics integrated into adaptive platforms can support students' learning needs and reduce disengagement. Likewise, AI features promote social presence and regulate collaboration through automated prompts for peer grouping and group reflections. Farrokhnia et al. (2025) found that AI-driven approaches promote group collaboration and engagement in online environments. Such systems foster connection and motivation to plan, monitor and reflect on tasks, which reflects enhanced self-regulation practices in learning.

Collaborative Learning and Peer Engagement Strategies

Collaborative learning represents a critical context for enhancing and developing self-regulation in engineering education. Self-regulation is often perceived as an individual cognitive process, but recent research has stressed its social and situated aspects. Collaborative learning and peer engagement strategies are emerging as effective mediating factors in remote learning environments (Hadwin et al., 2011). Students are required to interact and engage in socially shared regulation, coordinating and connecting individual self-regulation practices with peers to achieve shared goals. The link between collaborative learning and self-regulation is bidirectional. Effective collaboration requires students to monitor their own contributions relative to group needs, control impulses and participate or withdraw from discussions, and evaluate their collaborative strategies for effective learning (Järvelä & Hadwin 2013). Peer interaction offers opportunities to model effective self-regulation strategies, receive feedback on regulatory approaches, and engage in metacognitive dialogue, making the regulation process explicit (Schunk & Zimmerman, 2007).

In remote engineering laboratories, face-to-face collaboration is limited. Integrating well-designed online collaborative features in the remote laboratories can foster individual and shared regulatory processes. It enables students to set up individual and collective goals, monitor progress through digital tools and adjust their learning strategies (Abouelenein et al., 2025). Early and sustained peer interaction provides structure for accountability, which is a valuable component of self-regulation that helps students monitor their progress and persist with learning tasks. Students who demonstrate early course engagement tend to sustain the behaviour throughout the course. However, low-engagement students struggle to improve over time (Mena-Guacas, 2025).

Previous research has emphasised the significance of collaborative structures as moderators of self-regulation. Conventional discussion-based learning often fails to foster meaningful peer social interaction (Abouelenein, 2025). Dosoftei and Alexa (2024) observe that peer teaching strategies encourage students to plan and articulate themselves properly, enabling them to grasp complex concepts, improve communication skills, and increase their motivation to learn. Students participating in peer teaching strategies demonstrate superior technical knowledge and greater awareness of the learning process. Doulougeri et al. (2024) examine the adoption of challenge-based learning strategies in engineering education to enhance student participation and engagement. Integrating real-world problems into learning activities facilitates multidimensional learning where students set shared goals, and plan, monitor, and reflect on progress as a team. This evidence links peer interaction, collaboration, and regulation to enhanced academic achievement.

Student Satisfaction and Motivation in Online Learning Environments

The effectiveness of self-regulation practices in remote laboratories in civil engineering education is fundamentally shaped by the technological environments in which learning occurs. Unlike traditional face-to-face laboratories, where environmental cues (instructor presence, peer activity, physical equipment) naturally scaffold regulatory processes, remote environments require explicit design of regulatory support. Online learning environments and online communities provide affordances and constraints for self-regulation processes (Azevedo & Gašević 2019).

Design Features of Online Learning Environments that Support Self-Regulation

Engineering students are expected to develop both technical and professional skills. Student satisfaction and motivation are essential factors for effective remote learning in engineering education. Al-Khatib et al. (2024) found that the quality of course design, instructor availability and support, technological reliability, and opportunities for peer interaction significantly predict engineering students' satisfaction in distance learning. The course design quality, instructor accessibility and support, technological reliability, and opportunities for peer interaction all reflect the factors influencing satisfaction in remote learning for engineering students. The design and features of online learning systems facilitate prompt, regular feedback, peer interaction, and clear communication of learning needs and expectations, leading to greater student satisfaction. Each of the elements provides structural and motivational scaffolds for self-regulation.

Online Communities as Contexts for Socially Shared Regulation

While online learning system features offer structural support for self-regulation, online communities and peer interaction are crucial for socially shared regulation of learning (SSRL). The communities allow students to collectively plan learning and monitor performance to achieve the shared goals (Hadwin et al., 2011). Unlike static course management tools, online discussion forums and virtual lab teams create a social context that enables students to set shared goals, interact, and exchange strategies collaboratively. The teams create a sense of belonging and shared purpose that nurtures intrinsic motivations, autonomy, and confidence in managing learning tasks. Research emphasises that well-structured online discussion forums can also foster environments for practising self-regulatory strategies in remote learning.

Challenges in Technology-Mediated Self-Regulation

Technology-mediated environments introduce distinctive barriers to self-regulation. Research evidence has shown that many learners struggle to adapt to the autonomy required in remote learning environments (Eberle &Hobrecht, 2021). Only a few learners demonstrate strong self-regulatory skills, such as active participation, consistent engagement, and timely assignment submission (Pérez-Sanagustín et al., 2020). Students with slow engagement and a lack of self-regulation skills tend to demonstrate decreased motivation, suggesting insufficient regulatory control. Research has also highlighted social isolation, technical difficulties, and limited practical engagement as common problems associated with online learning (Gillett-Swan, 2017). These challenges impact students' ability to sustain participation and engagement. As such, students often struggle with planning, monitoring, and reflecting on their performance (Jarrah, 2025). Blended learning, which combines flexibility with structured feedback and social presence in conventional classrooms, is recommended for fostering regulatory competencies.

In summary, technology-mediated learning environments shape self-regulation in remote civil engineering education through multiple mechanisms. Effective online learning environments provide explicit regulatory scaffolds (progress tracking, deadline reminders, resource organisation tools) that compensate for the absence of physical environmental cues. Online communities extend individual self-regulation into socially shared regulation, enabling peer modelling, feedback, and collaborative metacognitive dialogue. However, these affordances must be intentionally designed; without explicit attention to regulatory support, online environments can increase cognitive load and undermine self-regulation. The implications for remote laboratory design are clear: technological infrastructure should be evaluated not only for content delivery effectiveness, but also for its capacity to support the full cycle of self-regulated learning.

Challenges and Limitations in Remote Learning Implementation

Innovative self-regulation strategies, combined with technology-enhanced learning initiatives, have shown great potential in increasing student engagement in learning. Their implementation, particularly in engineering education, has been confronted with immense challenges and obstacles, though. Matarneh et al. (2025) examined obstacles to the effective implementation of e-learning initiatives in engineering education and found that poorly developed technical infrastructure, technology-based problems, and a lack of institutional readiness were major obstacles that hampered effective e-learning implementation. Engineering students with low socioeconomic status might have difficulties with access to stable internet, electronic devices, and suitable learning spaces. This promotes learning disparity and inequalities in relation to economically privileged students. Their study recommended that institutions implementing remote learning with technology-based platforms should consider potential technological and socioeconomic barriers that impact student participation.

Institutional and departmental preparedness is essential for successful remote learning implementation. The rapid transition from classroom-based learning to online or remote learning during the COVID-19 pandemic exposed gaps in instructor preparedness for remote learning. Previous research supports this view, indicating that many instructors demonstrate inadequate pedagogical knowledge and practical skills, and lack the institutional support needed to create sustained remote learning experiences (Matarneh et al., 2025). These challenges highlight the need for engineering faculties to implement programmes that support instructors by providing the technological and pedagogical knowledge necessary to implement and deliver effective online learning.

Saldívar-Almorejo et al. (2024) explored challenges associated with implementing STEM education in engineering contexts. The findings indicated that poorly implemented remote learning initiatives make it challenging to replicate traditional engineering learning outcomes, including hands-on laboratory experiences, problem-solving skills, and practical visualisation of designs.

Significant literature evidence demonstrates relationships between these challenges and variations in student adaptation to online learning environments. Analysis of student engagement in remote learning revealed that these initiatives influence higher motivation, engagement, and satisfaction in some students more than in others. Findings from studies indicated that low forum participation rates in remote learning could indicate challenges in students making meaningful social interactions and collaborating with peers to create compelling learning experiences (Hadwin et al., 2011). Consequently, some students may thrive while others struggle in remote learning environments.

Social isolation is a prevalent concern among students in online learning environments. Research has confirmed that students report feeling isolated and disconnected from others, from teachers, from and online communities (Jarrah, 2025). Social isolation has negative effects on student motivation, engagement levels, and psychological well-being. The effect is more pronounced among engineering students who are required to develop technical and problem-solving skills through continuous engagement in hands-on laboratory experiments and collaborative learning activities.

Assessment and academic integrity concerns are critical barriers to successfully implementing remote learning. Some instructors have raised concerns about potential challenges in student assessment, such as academic dishonesty, particularly assignment cheating, which impacts the validity and reliability of these practices (Saldívar-Almorejo et al., 2024). Future research should focus on assessment practices that maintain academic rigour and integrity while acknowledging constraints associated with remote delivery.

Counterarguments and critical perspectives

Previous research confirms the effectiveness of innovative self-regulation practices combined with technology-driven initiatives in remote learning within engineering education. However, technology and its implications for future remote learning remain significant areas of debate. Critics of remote learning argue that integrating technological innovations with self-regulation practices disadvantages students from low socioeconomic backgrounds. Research has consistently demonstrated that students from low socioeconomic backgrounds lack access to stable internet connectivity, have fewer resources to obtain smart devices, and live in conditions that are less supportive of learning (Matarneh, et al., 2025).

Engineering students need special software to facilitate hands-on laboratory activities and collaborative learning experiences, which could be expensive and require stable, high-speed internet. The assumption that online learning would benefit all students equally overlooks systemic problems that may create widespread disparities in students' learning achievements. These concerns have been demonstrated by studies reporting significant variations in student engagement patterns in remote learning. A study on student engagement patterns in online learning indicated that 12% excelled while 53% did not perform well in remote learning, highlighting variations in adaptation to learning processes (Hadwin et al., 2011). Accordingly, critics have expressed concerns about the scalability and inclusivity of remote learning in engineering education.

Engineering students need special software for laboratory experiences and cooperative learning, which are essential parts of their education(Maceira et al.,2011). Unfortunately, this software is expensive and, requires a fast and reliable internet connection. Therefore, the assumption that remote learning is suited for all students ignores these basic, systemic issues. Students with these accompanying conditions cannot perform the same as others, by any estimation.

Rapid technological advancements represent another area of concern, with critics disagreeing about whether technology is likely to replace rather than complement human interaction and support pedagogical relationships in remote learning(Selwyn,2011) The literature has demonstrated that AI-based learning approaches enable personalisation and automated feedback, and encourage self-regulation practices (Jarrah, 2025). Critics argue that these practices undermine the bond between students and teachers. They also reduce opportunities for students to learn and work together, both of which are vital to meaningful learning, particularly in engineering education. The concern is that technology-based learning reduces students' dependence on instructors, which affects their confidence, engagement, and motivation (Merino-Campos, 2025). One study associated low participation rates in forums with subsequent social isolation and diminished instructor interaction that accompanies online learning programmes (Hadwin et al., 2011). These issues highlight the challenges of remote learning in simulating the social and collaborative settings found in traditional engineering learning environments. According to critics, these settings are essential for cultivating professional and technical competencies in engineering professions.

The long-term effectiveness and sustainability of remote learning have also been questioned. Substantial research has reported positive effects of integrating advanced technology-based learning initiatives in remote learning of engineering students, demonstrating the ability to enhance student engagement, motivation, and satisfaction (Li & Liang, 2024; Faza & Lestari, 2025; Mena-Guacas et al., 2025). However, critics contend that the rapid flow of technological change ensures that certain technologies are not likely to have a very long shelf life. This generates the necessity for significantly larger ongoing investment and training in affordable alternatives to keep programmes aligned with the evolving needs and wants of distance learners. This brings into question the affordability and feasibility of integrative technology-based programmes in distance learning.

The autonomy aspect of remote learning is highlighted in various studies as a key concern, especially for students who benefit from face-to-face learning environments. Self-regulation skills vary among students, with some experiencing difficulties adapting to technology-enhanced remote learning (Faza & Lestari, 2025). While the broader view suggests that students can effectively self-regulate in remote learning, there is significant evidence indicating variations in cognitive abilities, motivation, and preferences among students in remote learning environments.

The quality and depth of learning in remote learning have also been criticised. Studies comparing remote learning environments with traditional classroom-based environments have reported that students in traditional classroom-based learning demonstrate superior hands-on laboratory experiences and competency (Li & Liang, 2024). Physical engineering laboratories were found to be providing more problem-solving experiences and real-life applications of concepts than virtual laboratories. These variations were attributed to obstacles such as struggles with navigating and using high-level technologies. Students in remote learning environments may develop theoretical knowledge but lack the technical skills and intuitive understanding of engineering concepts needed for real-world applications.

Towards an integrated framework: technology-mediated self-regulation in remote civil engineering education

The literature reviewed reveals a fragmented understanding of self-regulation in remote engineering education, with studies examining individual components (technology tools, self-regulation strategies, engagement outcomes) in isolation. Student engagement in remote civil engineering laboratories is determined by the interaction of these interconnected components, as shown in Figure 1 below.

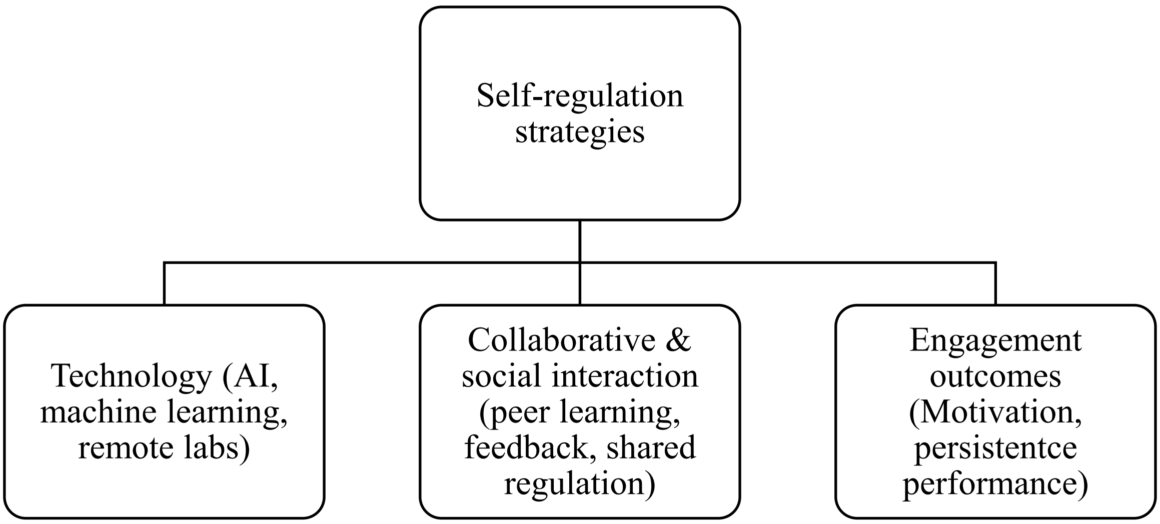

Figure 1: Interaction of self-regulation strategies, technological tools, collaborative engagement and learning outcomes influencing student engagement and participation in remote laboratories in civil engineering education

Gaps and Limitations

Notable gaps emerge in existing research. Many studies describe the innovative self-regulatory practices in remote learning rather than validating their long-term impact on students' learning outcomes. There is limited quantitative evidence linking specific self-regulation strategies to measurable improvements in student learning outcomes, including experiences and satisfaction. While technology such as AI and virtual labs is widely explored, research examining how they address individual differences, such as students' prior knowledge and motivation, is scanty. Research is also fragmented, emphasising technological affordances with little consideration of the pedagogical alignment or institutional readiness. The cross-cultural variation of self-regulation strategies among students in remote engineering education is underexplored, limiting the generalisability of findings. Moreover, the educator role and faculty and institutional support efforts, which are suitable for enhancing self-regulation in remote learning, have received limited attention.

Synthesis of key findings

This section presents a synthesis of key findings from the literature review and emerging themes. This review revealed opportunities and challenges associated with enhancing student engagement through innovative self-regulation initiatives in remote learning. The review uncovers evidence confirming previous research findings supporting the effectiveness of self-regulation practices in enhancing student engagement in remote learning (Hadwin et al., 2011; Faza & Lestari, 2025; García-Ramírez, 2025; Mena-Guacas et al., 2025) There is consistent evidence linking self-regulation behaviours—reflected through proactive time management, consistent login patterns, and increased assignment completion—with higher student engagement levels and improved academic performance. These findings validate self-regulation practices as effective educational interventions for enhancing student engagement, motivation, and satisfaction in remote learning environments (Hadwin et al., 2011).

Collaborative learning and peer interaction emerged as important factors and drivers of enhanced student engagement in remote learning (Hadwin et al., 2011; Dosoftei & Alexa, 2024; Doulougeri et al., 2024). Technologies such as AI, machine learning algorithms, virtual reality, and augmented reality support collaborative learning, providing enhanced learning experiences (Li & Liang, 2024; Suhail et al., 2024; Escobar-Castillejos et al., 2025; Mena-Guacas et al., 2025; Merino-Campos, 2025). Despite these benefits, current research indicates that many students face challenges developing meaningful peer interactions owing to increased isolation and disconnection from peers associated with remote learning approaches.

Students in remote learning engage in collaborative activities through virtual laboratories, experiments, and group discussions, which enhances their engagement levels. Students who demonstrate minimal engagement and low participation rates early in courses also show low participation and engagement later. This suggests that remote learning environments alone are insufficient for promoting enhanced student engagement, highlighting the need for increasing social interaction and peer collaboration tasks in remote learning.

Implications for educational practice

The literature synthesised in this review has implications for civil engineering education and other fields within engineering education. The evidence supports integrating innovative self-regulation initiatives into engineering curricula to enhance student engagement in remote learning. The findings confirm positive effects of self-regulation behaviours on students' learning engagement, motivation, and satisfaction. Integration of metacognitive strategies, goal setting, and development of self-monitoring abilities is encouraged as it fosters enhanced engagement.

Research has shown efficiency and improvements in assignment completion among high-engagement students. These learning experiences, combined with autonomy in remote learning, can be effective in enhancing students' engagement. Education experts designing curricula for remote learning are encouraged to consider incorporating structures and support that assist students in autonomously developing superior learning experiences while enhancing their self-regulation capabilities (Hadwin et al., 2011).

Focus should be directed towards pedagogical goals, students' needs, and the quality of technology implemented to enhance remote learning. Prior studies have shown that technologies supported by thorough educational structures are more effective than standalone technological interventions in promoting active learning, engagement, and collaboration (Escobar-Castillejos et al., 2025). This encourages educational institutions to invest in programmes that promote technological and pedagogical improvements among engineering students in remote learning.

Inequality and disparities in access to remote learning resources are major concerns that could impact the future of remote learning in engineering. Research has shown that many students struggle to adapt to remote learning, with some disadvantaged by their socioeconomic backgrounds, which limit their ability to access necessary, reliable internet and electronic devices (Hadwin et al., 2011). Institutions are encouraged to establish systems that support students from disadvantaged backgrounds in accessing materials and benefiting equally from remote learning.

Recommendations for future research

It is necessary to conduct longitudinal research that examines the fundamental dimensions of the long-term effects of implementing self-regulation initiatives and technology-driven strategies. Special attention should be paid to issues affecting student engagement and outcomes in remote learning over time. Much of the current research focuses on short-term impacts of educational interventions, which may not demonstrate their full impact on student learning and development.

Long-term, unfunded research is required to investigate the grassroots movement's long-term effects. The extant literature, covering just a few years, makes the case that something significant is afoot. For the movement to have real impact—on engagement, pedagogy, and actual student outcomes — there is need for some real, long-term studies.

There is a knowledge gap regarding differences in student responses to technology-based learning initiatives in engineering education. This review revealed several remarkable variations in how well students adapt to remote learning, suggesting that technology integration may not be sufficient, especially for students who benefit from classroom-based learning environments or "traditional" classrooms. Future research should focus on investigating how student academic preparation, learning requirements, and preferences, including social and economic backgrounds, influence remote learning approaches.

The results of the present study indicated that there may be gaps in student engagement and collaboration, as many students showed low participation rates in remote learning. Future research must focus on evaluating and establishing successful tactics that encourage peer interaction in distance learning environments. Researchers should study the viability and affordability of technology-enhanced distance learning. Concerns have been raised over the financial sustainability and scalability of advanced technologies integrated into educational programmes.

Limitations and future directions

This review acknowledges several limitations. One limitation is the choice of publication date. This choice may have excluded some potentially eligible studies that would have provided additional context and theoretical understanding. Nevertheless, reviewing and evaluating studies published between 2020 and 2025 allowed us to capture the most current trends, opportunities, and challenges associated with innovative self-regulations in remote learning in engineering, particularly those relevant to future engineering education.

The heterogeneity of study designs and technological interventions across reviewed studies limits the ability to analyse the effectiveness of different technologies in enhancing student engagement in remote learning. Future reviews of standardised technologies integrated into remote learning would benefit future educational practices and enable the implementation of effective programmes to improve student engagement.

Conclusion

This systematic review provides an understanding of current trends, opportunities, and challenges in integrating self-regulation practices and technology to enhance engineering students' engagement in remote learning. Technologies such as AI, virtual reality, and augmented reality are integrated with innovative self-regulation initiatives for personalised learning experiences. These educational interventions improve peer interaction, participation rates, collaboration, and academic satisfaction in remote learning.

Pedagogical principles and technological integration are essential drivers of the successful implementation of self-regulation initiatives in remote learning. Institutions should provide the necessary support to prepare faculty for integrating essential interventions that have a greater impact on student engagement and learning outcomes. These processes play crucial roles in achieving active learning, motivation, collaboration, and satisfaction for engineering students.

Various problems and obstacles hamper the deployment of self-regulation strategies in distance learning. Equitable access to required materials is essential for ensuring that engineering students benefit equally from distance learning. Some students are disadvantaged by their socioeconomic backgrounds, and this hinders access to resources vital to remote learning. Disparities in access to learning materials impact students' participation rates, engagement levels, and practical skills, particularly for those from low socioeconomic backgrounds.

The opportunities and issues highlighted in this review extend beyond civil engineering education to the future of broader educational practice. Lessons learned from technology integration in engineering education can guide the implementation of educational interventions supported by technology for effective outcomes. While there is evidence supporting the benefits of self-regulation practices on enhancing student engagement in remote learning, realising these benefits requires evidence-based support to overcome known challenges, including equity and inclusion barriers.

An increasing number of researchers are urged to study the intersection of educational interventions and technological progress in the realm of remote learning. They are asked to approach the topic from the angle of different academic disciplines. Their work is hoped to illuminate what is unique to the remote learning model in terms of each discipline's opportunities and challenges. In addition, future researchers are encouraged to explore existing strategies that might enhance peer interaction and engagement in such settings, emphasising the highly valued traits of practicality and cost-effectiveness. This review advances understanding of self-regulation in remote civil engineering education in several ways.

Disclosure

Conflict of interest

The author declares no conflict of interest

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