2.13

Fostering Self-Regulated Learning Among Engineering Students

Shan Tuyaerts[a], Lynn Van den Broeck[b], Vicent Rutagangibwa[c], Peter Ruijten-Dodoiu[d], and Tinne De Laet[e]

[a] KU Leuven, Belgium, ORCID: 0000-0001-5107-7524;
[b] KU Leuven, Belgium, ORCID: 0000-0002-6276-7501;
[c] Mbarara University of Science and Technology, Uganda, ORCID: 0009-0009-2017-9654;
[d] Eindhoven University of Technology, the Netherlands, ORCID: 0000-0003-1900-3415;
[e] KU Leuven, Belgium, ORCID: 0000-0003-0624-3305.

Keywords: *self-regulated learning, metacognition, case study, engineering students, intervention design*

Self-regulated learning (SRL) is increasingly recognised as a core competency for engineering students, who must navigate complex, multidisciplinary problems and continuously adapt their learning throughout their careers. This chapter introduces SRL through three complementary theoretical models: Zimmerman's cyclical phases, Boekaerts' dual processing model, and Hadwin et al.'s socially shared regulation of learning framework, thus highlighting the cognitive, emotional, and social dimensions that shape how students plan, monitor, and evaluate their learning. Eight SRL intervention archetypes are used to provide a practical structure for educators to design or select interventions that fit their context. To illustrate how SRL can be fostered in practice, we present three case studies from different institutional and cultural contexts, demonstrating varied approaches to embedding SRL through reflection, peer support, direct instruction, and technology-enhanced scaffolding. The chapter concludes with ten recommendations for creating effective interventions that foster SRL among engineering students.

DOI: 10.59490/mt.266.69.

1 Definition: the concept of self-regulated learning

1.1 What is self-regulated learning?

Self-regulated learning (SRL) involves proactively setting goals, planning how to achieve them, self-motivation, monitoring progress, and reflecting on what was effective and what was not (Zimmerman, 2002). It is a process characterised by an internal feedback loop through which learners actively manage their learning (Butler & Winne, 1995). Learners take agency over their own learning process, continually adapting it to specific learning tasks and improving it over time (Butler & Winne, 1995; Zimmerman, 2002).

1.2 Theoretical models of SRL

Various theoretical frameworks describe the components, processes, and strategies underpinning SRL (Panadero, 2017). Each offers a distinct perspective and emphasis. This chapter presents three widely used models that provide complementary insights into the construct of SRL: Zimmerman's cyclical phases model, Boekaerts' dual processing model, and Hadwin et al.'s socially shared regulation of learning framework. These models emphasise the individual, emotional, and social dimensions of SRL, respectively.

Zimmerman's cyclical phases model — individual dimension

Zimmerman's model (2002) is characterised by its cyclical nature and involves three learning phases: (1) the forethought phase, in which learners set goals for themselves and determine what steps to take to achieve those goals; (2) the performance phase, in which learners implement their chosen strategies and monitor their learning activity and progress towards the goal; and (3) the self-reflection phase, during which learners look back on whether they have achieved their original goal and evaluate the effectiveness of the learning activity. The self-reflection phase informs the next forethought phase, underscoring the cyclical nature of SRL, making it a dynamic and evolving process of continuous improvement.

Boekaerts' dual processing model — emotional dimension

Boekaerts' dual processing model (Boekaerts, 2011) states that learners regulate their behaviour through two parallel pathways, and that emotions triggered by a task determine which pathway becomes dominant.

Learners follow the *mastery pathway* when they experience positive and manageable emotions toward a task. Their learning goals feel meaningful and attainable, which creates alignment between what the task requires and their own well-being. On this pathway, learners invest effort, develop competencies, and use effective learning strategies. Learners shift into the *well-being pathway* when a task triggers negative emotions, such as stress, confusion, frustration, or threat. Here the learner's main goal becomes protecting their emotional well-being, not completing the task. This may result in avoiding the task, postponing work, or narrowing attention to reduce discomfort. Although learners may initially move into the well-being pathway, they can shift back toward the mastery pathway when they feel a sense of commitment, for example a commitment to personal goals, to an assignment deadline, to their project team or teacher, or to their own standards of performance. These commitments give learners a reason to re-engage with the task, even when emotions can still be negative. This shift can be supported by *internal factors*, such as autonomous motivation, self-efficacy, or personal values, or *external factors*, such as expectations from peers, instructors, or assessment requirements.

Boekaert's dual processing model highlights that emotions are not side effects of learning, but that they actively shape SRL. Learners' behaviour under time pressure, performance demands, or uncertainty can be understood as movement between the two pathways. Effective SRL support therefore requires focusing not only on strategies, but also on the emotional context in which students regulate their learning.

Socially shared regulation of learning (SSRL) — social dimension

Hadwin et al. (2011) state that regulation occurs in social and interactive settings, highlighting how SRL is not only an individual process. It distinguishes three modes of regulation in collaborative settings: (1) self-regulation at the individual level (SRL), in which learners adapt their own actions to group interactions; (2) co-regulation (CoRL), in which one person takes the lead in regulation, motivating others to practise regulatory behaviours; and (3) socially shared regulation (SSRL), in which the whole group deliberately and jointly regulates their learning.

This model is especially relevant in engineering education, where teamwork is central to capstone projects, design challenges, and problem- and inquiry-based learning environments.

1.3 SRL and related competencies

As shown above, SRL models vary in focus. Some emphasise SRL's cyclical nature (Zimmerman, 2002), others its emotional (Boekaerts, 2011) or social dimensions (Hadwin et al., 2011). These models also differ in whether related competencies are seen as influences or subcomponents of SRL. This chapter focuses on four competencies that are important for success in engineering education and practice, regardless of their classification: self-direction (Conway et al., 2022), self-reflection (Zimmerman & Moylan, 2009), autonomous motivation (Schunk & Zimmerman, 2007), and feedback literacy (Butler & Winne, 1995). Table 2.13.1. presents how these four competencies are connected to the three SRL models.

Table 2.13.1. Mapping between the four competencies and the SRL models of Zimmerman, Boekaerts, and Hadwin.

	Zimmerman (individual)	*Boekaerts (emotional)*	*Hadwin (social)*
Self-direction	The forethought phase includes planning, goal-setting, and strategy selection. In the performance phase the learner has to maintain direction. During the self-reflection phase a learner should redirect and redefine the (learning) direction.	Learners switch between mastery and well-being pathways, exercising agency when deciding how to proceed with a task.	Groups co-construct goals, assign roles, and coordinate strategies in shared regulation episodes. Within the group, individuals also have to be self-directed.
Self-reflection	Central in the self-reflection phase (self-evaluation, attribution, adaptive reactions).	Emotional awareness and meaning-making drive shifts between pathways; reflection helps learners re-engage.	Teams engage in collective monitoring and reflection on progress and decisions. Individuals in teams need to self-reflect.
Autonomous motivation	The forethought phase includes self-efficacy, task value, outcome expectations, and motivation beliefs. The performance and self-reflection phase requires self-control and self-reflection, which are subject to motivation.	Motivation drives movement from the well-being pathway back to the mastery pathway; learners persist because goals matter.	Group belonging and collective goals can strengthen motivation, but this is not the primary focus of the model.
Feedback literacy	Feedback (internal and external) informs monitoring and adaptation within and across cycles.	Emotional reactions affect how feedback is received and acted upon.	Co- and shared regulation depend on giving and receiving feedback.

2 SRL across engineering education

Effective SRL helps students take ownership of their learning and improve it over time. While valuable across disciplines, it is particularly important in engineering education, which often employs approaches such as problem-based and collaborative learning that require students to become autonomous, adaptable learners (Hernández-de Menéndez et al., 2019). Engineering programmes expect students to develop competencies such as critical thinking, adaptability, and resilience, which can be fostered through SRL. Such competencies are crucial not only for academic success, but also for professional practice in engineering. As engineering is a rapidly evolving field, professional engineers must be capable lifelong learners to remain competitive. SRL is recognised as a core component of lifelong learning (Van den Broeck et al., 2024b). However, recent research suggests that engineering students may not attain a sufficient level of SRL by graduation, leading to a call from the industry for higher education to incorporate SRL development in engineering programmes (Tuyaerts et al., 2025b).

This importance of SRL is reflected in engineering education frameworks and professional standards worldwide. The ENAEE (2021), which oversees the EUR-ACE framework used across Europe, expects graduates to be prepared for independent lifelong learning. SRL supports autonomous and adaptive learning, contributing directly to this outcome. In the United States, the American Society for Engineering Education highlights persistence, motivation, and critical thinking as essential graduate attributes (Agrawal & Harrington-Hurd, 2016), competencies that are either part of or supported by SRL. Furthermore, ABET, the Accreditation Board for Engineering and Technology which sets widely used criteria for engineering programs in the United States and defines core student outcomes expected of engineering graduates (ABET, 2024), emphasises student outcomes such as problem solving, teamwork, professional judgement, feedback literacy, and the ability to acquire new knowledge independently. These are all capabilities that rely strongly on SRL processes. SRL supports these outcomes by helping students plan and monitor their work (self-direction), evaluate and improve their performance (self-reflection), stay motivated through complex tasks (autonomous motivation), and make effective use of feedback (feedback literacy).

3 Forms of implementation

3.1 SRL intervention archetypes

A recent systematic literature review by Tuyaerts et al. (2025a) identified eight distinct types of interventions designed to foster SRL in higher education, referred to as SRL intervention archetypes. Tuyaerts' typology with eight archetypes aims to offer a practical typology to understand, compare, and select approaches for supporting SRL across disciplines. Although these archetypes provide a helpful structure for navigating the wide variety of SRL interventions, they should not be viewed as exhaustive, mutually exclusive, or universally applicable. Educators can combine elements across archetypes or adapt them to fit their instructional goals and constraints.

T1: Indirect technology-facilitated SRL instruction interventions without teacher feedback

T1 interventions incorporate digital tools into their setup. Rather than teaching SRL directly, they guide students through SRL processes such as planning, monitoring, and reflecting, potentially without students realising they are engaging in SRL. This approach may help students develop habits that lead to automatic regulation of learning, based on their experience with the intervention. Teacher feedback is absent, freeing up staff resources, though feedback may be generated automatically via technology. For example, interventions may display analytics in a learning management system (Banihashem et al., 2022), provide automatic feedback on assignment correctness (Daradoumis et al., 2021), or support learning by offering prompts via a pedagogical agent (Cerezo et al., 2020).

T2: Indirect SRL instruction interventions with teacher feedback

T2 interventions combine indirect SRL instruction, where students engage in the SRL cycle without explicit instruction on SRL concepts with teacher feedback. Teacher-provided feedback may relate to module content or learning processes, but not to SRL itself, as students do not receive direct SRL instruction. Students can use this feedback to learn about their performance, informing their own evaluation processes and indirectly training their self-reflection competency.

T3: Direct standalone SRL instruction interventions

T3 interventions provide direct SRL instruction outside the regular curriculum, such as in an elective module (Reeves & Stitch, 2011). They are typically flexible and can be offered to students across programmes as a separate module or training, allowing them to be easily reused. Direct SRL instruction allows students to learn about SRL theory, such as Zimmerman's cyclical model, and strategies like goal setting or self-evaluation. Facilitators may need to familiarise themselves with SRL theory and concepts before they can effectively deliver these interventions.

T4: Direct embedded SRL instruction interventions

Unlike the standalone interventions of T3, T4 interventions are integrated into subject-specific content and modules. This approach demonstrates the relevance of SRL to students' academic work and allows them to apply SRL strategies in authentic contexts. Students receive direct SRL instruction and apply it to real learning tasks. Subject-specific strategies, such as vocabulary learning (Zhang et al., 2024), help bridge SRL theory and practice, encouraging SRL as a natural part of the learning experience.

T5: Peer-driven interventions

T5 interventions rely on peer interaction to drive SRL development. Peers can both refer to more experienced students acting as tutors (Fernandez-Martin et al., 2022) or monitors (Reeves & Stitch, 2011), or to students of the same level who provide support as equals, such as peer assessment or feedback (Contreras Soto et al., 2023) and peer-led study groups (Atwa et al., 2019). What distinguishes this type is the intentional and structured peer engagement, which goes beyond typical group work. If direct SRL instruction is included, students may require training to support others effectively.

T6: Self-paced self-study interventions

These interventions allow students to decide when and how to engage with the learning materials. Once content, such as a study skills app (Baars et al., 2022), is prepared and made available, students work through it independently, without scheduled sessions. This format promotes student autonomy and responsibility, key elements of learner agency and SRL. While setup requires preparation and development, ongoing facilitation is minimal.

T7: Documented reflection-driven interventions

These interventions use structured written reflections to support SRL through introspection. Formats such as learning diaries (Fabriz et al., 2014) and online portfolios (Nguyen & Ikeda, 2015) help students reflect on their learning, track progress, and identify strengths and weaknesses. The reflective process over time allows students to revisit entries to support their learning process.

T8: Personalised data-driven interventions

These interventions use technology-mediated feedback and content to individual students based on data collected during the intervention. As a result, all such interventions require technological support. Tools such as learning analytics dashboards (Banihashem et al., 2022; Sauchelli et al., 2024) and AI tutors (Lee et al., 2024), aim to provide personalised feedback (Chu et al., 2023) or reflection prompts (Cerezo et al., 2020). Personalisation is automated, making these interventions scalable and responsive to individual needs and development stages without additional effort.

Connecting archetypes to the three SRL models

Although the archetypes leave ample room for concretisation and specialisation, it is useful to consider how they generally align with the main perspectives of the three theoretical SRL models presented earlier. Zimmerman's model emphasises a cyclical and predominantly individual form of regulation, Boekaerts' model foregrounds the emotional and motivational dimension of regulation, and Hadwin's model highlights the social dimension through co- and socially shared regulation. Table 2.13.2 presents a connection between the eight SRL archetypes and the three SRL models, illustrating where strong, moderate, or limited alignment can typically be expected.

Table 2.13.2: Connecting the eight SRL intervention archetypes to the three SRL models. Dots represent the degree to which the SRL intervention archetype is connected to the SRL model.

SRL intervention archetype	*Zimmerman (individual)*	*Boekaerts (emotional)*	*Hadwin (social)*
T1: indirect tech-facilitated (no teacher feedback)	●●	●	●
T2: indirect SRL with teacher feedback	●●	●●	●
T3: direct standalone SRL instruction	●	●	●
T4: direct embedded SRL instruction	●●●	●●	●●
T5: peer-driven interventions	●●	●●	●●●
T6: self-paced self-study	●	●	●
T7: documented reflection-driven	●●●	●●	●
T8: personalised data-driven	●●	●	●

Table 2.13.3: Mapping between the three SRL models and the three case studies. Dots represent the degree to which the case study is mapped to the SRL model.

	Zimmerman (individual)	*Boekaerts (emotional)*	*Hadwin (social)*
Case study 1: Process-based learning through reflection cycles (TU/e)	●●	●	●●●
Case study 2: Reflection for learning equity (MUST)	●●●	●●	●
Case study 3: Longitudinal SRL intervention (KU Leuven)	●●●	●	●

3.2 Three case studies

This section presents three case studies illustrating how SRL interventions can be implemented in practice. We connect these case studies explicitly to the three theoretical SRL models of Section 1 (Table 2.13.3) and the eight SRL archetypes of Section 3 (Table 2.13.4). Hereby we provide practitioners with real-world examples on how to connect SRL interventions to SRL theory, Tuyaerts' SRL intervention typology, and particular SRL competencies.

Table 2.13.4: Mapping of case studies to the SRL archetypes. ●●● = primary alignment/core design; ●● secondary alignment (intentional but not central); ● supporting alignment (present but not core); ○ not applicable/no meaningful alignment.

SRL archetype	*Case 1: process-based learning through reflection cycles (TU/e)*	*Case 2: reflection for learning equity (MUST)*	*Case 3: longitudinal SRL intervention (KU Leuven)*
T1: indirect tech-facilitated SRL (no teacher feedback)	○	○	○
T2: indirect SRL instruction (teacher feedback)	● (coach feedback on process)	●● (instructor reading & guiding journals)	○
T3: direct standalone SRL instruction	○	○	○
T4: direct embedded SRL instruction	○	○	●●● (core design across 3-year curriculum)
T5: peer-driven interventions	●● (peer coaches in central role)	○	○
T6: self-paced self-study	○	● (individually paced journaling)	● (self-paced SRL tasks across semesters)
T7: documented reflection-driven interventions	●●● (repeated, structured, written reflection	●●● (weekly reflections)	●● (reflections across modules/years)
T8: personalised data-driven interventions	○	○	○

The three case studies are drawn from the authors' institutional practice across Eindhoven University of Technology (TU/e) in the Netherlands, Mbarara University of Science & Technology (MUST) in Uganda, and KU Leuven in Belgium. Each was implemented by the authors or close collaborators within their regular teaching and programme-level responsibilities.

Case 1: Process-based learning through reflection cycles

Context. The Innovation Space Bachelor End Project (ISBEP) is a challenge-based learning module at Eindhoven University of Technology (TU/e) in which interdisciplinary student teams work on open-ended, real-world challenges (Ruijten-Dodoiu et al., 2024). Students from different engineering programmes collaborate with external stakeholders and are supported by a network of coaches and academic supervisors. The module is positioned at the end of the bachelor programme and is designed to foster both disciplinary knowledge and broader professional competencies such as SRL, collaboration, systems thinking, and reflection. The module was taught by one of the authors of this chapter and has the following intended learning outcomes (ILO):

Students are able to:

- Identify the needs of different stakeholders and integrate them in a viable solution;
- Identify the interdisciplinary problem that needs to be solved and its disciplinary components;
- Reflect on the role that they have played in the interdisciplinary team, and its impact on professional identity;
- Manage a situation where there is no clear answer to their problem;
- Integrate the individual components into a working/experiential demonstrator;
- apply the knowledge from different disciplines in a project and integrate them into a viable solution;
- communicate and collaborate with people from other disciplines.

Intervention design. This intervention implemented a process-based learning approach to support the development of broader professional competencies. The core idea was to move beyond traditional assessment of learning and instead focus on assessment for learning. This was operationalised through a developmental framework that described learning outcomes across four stages: beginning, emerging, proficient, and advanced. These stages were applied to a set of intended learning outcomes (ILOs) that captured key aspects of competence development in ISBEP. Each ILO was described in terms of observable behaviours and increasing levels of independence, providing students with a clear structure for self-assessment and growth.

Throughout the module, students engaged in a recurring reflection cycle, structured around seven time points. At each point, they assessed their own development, reflected on their learning process, and received narrative feedback from their process coach. These reflections were guided by prompts that encouraged students to articulate their goals, identify challenges, and plan next steps. The process was designed to support SRL by making development visible and actionable. In ISBEP, process coaches, often experienced students or alumni, are trained to guide students through the reflection cycle, provide formative feedback, and help them interpret their development in relation to the ILOs. These coaches used the reflections to tailor their guidance and to monitor student progress over time. Hence, SRL development is driven by peers, acting as process coaches, and repeated reflection. The intervention draws on active learning in authentic engineering contexts.

Implementation and sample size. The intervention was implemented with 29 Year 3 engineering bachelor students enrolled in the ISBEP module.

Data collection. Data included seven rounds of written reflections, narrative feedback from peer coaches, student interviews, and module evaluations conducted at the end of the module.

Data analysis. Reflections were analysed using qualitative coding focused on SRL behaviours (planning, monitoring, reflection), and interview data were examined for recurring themes related to self-awareness, emotional responses, and development over time.

Findings. During interviews and in module evaluations, students reported that the structured reflection process helped them clarify their learning goals and better understand their role within the team. They appreciated the long-term perspective on learning and the opportunity to track their development across multiple dimensions. Students did need support in developing reflective and metacognitive skills, especially early in the module. This highlights the need for scaffolding and guidance when implementing process-based learning approaches. Coaches found the framework helpful for providing targeted feedback and for facilitating meaningful conversations about learning and growth.

Conclusion. This intervention illustrates how a process-based learning approach can support the development of self-regulated learners in engineering education. By making learning visible, iterative, and reflective, students are empowered to take ownership of their growth and prepared for the complexities of professional practice.

Although the intervention was implemented in a small-scale module with 29 students, its structure is adaptable. The reflection cycles can be scaled by embedding them into existing module structures and by exploring the use of AI tools to support feedback and guidance at scale. The positive outcomes observed in ISBEP suggest that this approach holds promise for broader applications across curricula.

Case 2: Reflection as a tool for learning equity in engineering classrooms

Context. At Mbarara University of Science and Technology (MUST), a significant challenge emerged with the implementation of a revised engineering curriculum. A combined Digital Signal Processing (DSP) module now brings together third-year Biomedical Engineering (BME) students and third- and fourth-year Electrical and Electronic Engineering (EEE) students. Among these groups, only BME students have prior exposure to foundational technical concepts through a Signals and Systems module. In contrast, the EEE students encounter DSP content without any background. This misalignment has resulted in disparities in conceptual readiness, limiting engagement, and creating frustration among students, particularly those who are seeing the material for the first time.

Intervention design. To address this challenge, a structured reflective learning intervention was introduced during the first semester of the 2024/2025 academic year, spanning four months. SRL development is driven by repeated reflection in an authentic engineering context. Therefore, participants were guided to maintain weekly learning journals in which they documented their evolving understanding, conceptual challenges, and personal strategies for bridging knowledge gaps. Typical prompts included:

1. What concept challenged you most this week?
2. What strategy did you use to address this challenge?
3. What will you try differently next week?

These journals were not assessed for correctness but were reviewed for reflection depth and consistency of engagement. This approach encouraged honest self-exploration and created space for students to think critically about their learning processes. The intervention intentionally targeted the SRL competencies of self-reflection, self-direction, and feedback literacy by encouraging students to plan learning actions, monitor conceptual understanding, and evaluate strategy effectiveness across weekly cycles. Early observations from journal analysis indicated that the reflective practice helped students navigate uneven prior knowledge, strengthened learner agency, and supported equitable participation across cohorts.

Implementation. Before implementation, informed consent was obtained from all students in the class. They were clearly informed that the intervention was intended to support their self-directed learning and metacognitive development, and that participation would not contribute to coursework marks or influence academic grading in any way. All 130 students voluntarily agreed to take part in the initiative.

Sample size. The intervention involved 130 engineering students across the BME and EEE programmes.

Data collection. Data consisted of weekly written learning journals, complemented by informal instructor observations and selected student excerpts that illustrated shifts in understanding and engagement. Journal prompts required students to articulate learning goals, identify conceptual misunderstandings, describe strategies used, and plan subsequent learning actions, thus generating evidence of SRL processes.

Data analysis. Journal entries were analysed using an inductive thematic analysis focusing on observable SRL behaviours, including goal setting, monitoring of understanding, help-seeking behaviour, strategy adaptation, and reflective evaluation. These indicators were interpreted through Zimmerman's cyclical SRL phases to identify evidence of forethought, performance monitoring, and self-reflection across the semester. Instructor observations were used to triangulate emerging patterns of engagement and learning agency. Reflections were compared across multiple journal submissions throughout the semester to identify recurring patterns in learning challenges, strategy use, and developmental growth.

Findings. Preliminary analysis of the journals shows that students began identifying their own learning gaps and experimenting with new strategies, like peer discussion and revisiting lecture notes. One student wrote, *"I thought I understood convolution, but writing it down made me realise I was confused. I had to go back and ask for help."* Another shared: *"Reflecting weekly helped me track my understanding. I no longer wait for the lecturer; I now try to figure things out myself."* These reflections suggest a shift toward greater metacognitive awareness and learning ownership, consistent with Zimmerman's model of SRL (Zimmerman, 2002). Across reflections, students increasingly demonstrated metacognitive awareness, proactive help-seeking, and deliberate strategy adaptation, indicating strengthening self-reflection and self-direction competencies over time.

These observations support broader findings in the literature. Turns et al. (2014) argue that reflection enables learners to assign meaning to their experiences and use that meaning to guide future actions. In our context, students revisited their learning journeys through the lens of their personal experiences, enabling them to make connections between new DSP content and previously held knowledge. This interpretive process mirrors what Cimer et al. (2013) describe as the power of reflection to improve not only content mastery, but also self-perception and motivation. Similarly, Kori et al. (2014) note that reflective writing can foster self-explanation and help students recognise inconsistencies in their understanding, which was evident in our students' journals.

The reflections also revealed how curriculum design influences learner identity and perceived belonging. Some EEE students expressed feelings of inadequacy due to their lack of foundational knowledge, while BME students described a sense of validation. However, over time, reflective practice appeared to level this disparity, enabling all students to identify individual learning goals, work toward them independently, and reflect on their progress. This suggests that reflection, as a context-sensitive pedagogical tool, can promote equity in learning outcomes across structurally diverse classrooms.

Conclusion. This case study illustrates how integrating reflective practice into a technically demanding module can support SRL, student agency, metacognitive growth, and learning equity in diverse classrooms. Ongoing analysis of student journals will deepen the understanding of reflective learning patterns, with future efforts focused on scaling this approach across modules and building faculty capacity. The intervention requires minimal additional resources and can be adapted by embedding short reflective prompts within existing coursework, making it suitable for large or resource-constrained engineering classrooms. The experiences in the case study affirm that meaningful pedagogical change can begin with simple, context-responsive practices that encourage students to think critically about how they learn.

Case 3: Longitudinal SRL intervention across the bachelor programme

Context. A three-year SRL intervention was developed for integration into the Engineering Technology bachelor curriculum at KU Leuven. It was piloted at Ghent campus, embedded into the modules Dynamics and Energy and Vibrations and Waves in Year 1, Engineering and Economics and Statistics and Data Management in Year 2, and the Engineering Experience capstone in Year 3.

Intervention design. This intervention addressed the need for sustained SRL development and consisted of three overlapping stages aligned with study years. It begins with simplified direct SRL instruction based on Zimmerman's cyclical model, gradually building complexity over time. Materials were presented visually through infographics, followed by tests and practical applications. Assignment frequency was high at first and gradually reduced.

Year 1 focuses on supporting students' transition to higher education, aiming to raise awareness of their learning process and learner agency. SRL strategies, e.g., planning, learning strategies, and self-reflection, were directly introduced in relation to typical study tasks and mapped to Zimmerman's phases. Assignment design indirectly encouraged students to complete SRL cycles and to think ahead, fostering the continuous adaptation of their learning process.

Year 2 gradually shifted focus and incorporated both long- and short-term cycles. In the module in the first semester, students worked towards a self-chosen study goal, while short cycles on lab learning and individual deadline management characterised the second semester. These activities fostered autonomy and responsibility. In addition, SRL was introduced across different contexts to illustrate its relevance to academic, professional, and personal growth.

In the final year, students reflected on what type of engineer they wished to become and started working towards that vision, i.e., professional identity formation. Assignments were connected to compulsory industry visits and the campus job fair. The intervention ended with a look ahead, encouraging students to take ownership of their development through practicing SRL.

Implementation. The intervention was organised into semester-long learning modules on KU Leuven's Blackboard learning platform and came with a comprehensive manual, allowing instructors to easily copy and adapt materials to fit their needs. Student participation was compulsory, as the interventions were embedded in the regular curriculum.

In the first pilot phase, educational support was provided for setting up the semester-long learning modules. In a second pilot phase, the instructor implemented the semester-long learning modules independently.

Sample size. The longitudinal programme reached 280 engineering students across three-year levels, with full cohorts participating during the pilot phases.

Data collection. Data included module-SRL assignments, student reflections, planning tasks, and anonymised learning platform activity logs. Instructors also provided informal observations on student engagement and ease of implementation.

Data analysis. Quantitative data (e.g., task completion, timing, progression) were reviewed descriptively to track engagement patterns, while from a qualitative point of view written reflections and instructor notes underwent a light thematic analysis to identify recurring SRL behaviours and shifts in autonomy over time.

Findings. Compulsory participation in the pilot project was initially met with student resistance, which gradually gave way to appreciation. Students reported reduced stress during examinations thanks to a study schedule they would not otherwise have made themselves. Students reported participation required about 15 minutes per week on average. In the second pilot phase, an instructor who implemented the intervention independently of the research team reported that the materials were easy to adapt to their student cohort and appreciated the low-effort setup and maintenance of the intervention.

Conclusion. This longitudinal intervention fostered SRL through various strategies tailored to engineering students, while remaining scalable and adaptable. Students gradually recognised its benefits, while instructors appreciated its straightforward implementation and follow-up.

4 Recommendations for implementation/learning

The SRL models, SRL competencies, SRL archetypes, and three case studies provide a foundation for implementing SRL interventions into engineering education in order to foster self-regulated learning among engineering students. To conclude, we offer recommendations for you building on this chapter and the personal experiences from the authors.

Design interventions on solid SRL foundations. Design SRL interventions that explicitly draw on well-established SRL models (e.g., Zimmerman's cyclical model, Boekaerts' dual processing model, and Hadwin's SSRL) and ensure that activities target core SRL competencies such as self-direction, self-reflection, autonomous motivation, and feedback literacy. Use the eight SRL archetypes for inspiration.

Make SRL competencies and processes explicit. Make sure that teachers have a clear view of the SRL competencies and processes that the intervention is targeting. Furthermore, decide when and how to provide students with an explicit view on these competencies and processes (e.g., direct or indirect instruction).

Build SRL into a variety of tasks, including authentic engineering tasks. Integrate planning, monitoring, and reflection into regular engineering modules, but also design projects, lab work, or problem-solving assignments. When SRL activities are embedded in a variety of tasks and contexts, students more readily see their relevance and apply them meaningfully, and transfer their SRL skills to new tasks.

Start small and build incrementally. Practitioners do not need to immediately redesign entire programmes to support SRL. Begin with one intervention, such as a short reflection cycle, a self-assessment rubric, or structured peer feedback, and expand gradually building on the earlier experiences.

Aim for a longitudinal approach. A longitudinal approach helps students progress from guided practice in the first year to greater independence in later years. Spread SRL opportunities across different modules and contexts so students can refine competencies as tasks become more complex and are supported in developing long-term SRL competencies.

Offer regular opportunities for structured reflection. Use recurring reflection cycles, learning journals, or short check-ins that prompt students to articulate their learning goals, analyse their performance, and plan next steps. Scaffolding should be strongest early in the module or programme and gradually decrease as students gain confidence.

Use feedback strategically to develop feedback literacy. Combine external feedback (from instructors, peers, or learning analytics) with activities that require students to interpret and act on it. Encourage learners to compare their own self-assessment with external perspectives so they can calibrate their judgements and refine their strategies.

Leverage peer interaction to support co- and socially shared regulation. Integrate peer support, team-based reflection, or collaborative goal-setting. Peers can trigger productive SRL behaviours, and offer motivational support, especially in project-based or interdisciplinary environments.

Use technology intentionally when designing and executing interventions. Technology can be the teacher's assistant when developing and executing SRL interventions. Learning analytics dashboards, study planners, automated feedback systems, AI tools-tutors, etcetera can help students track their behaviour, set realistic goals, and make informed adjustments. Technology can moreover support teachers to cover larger student audiences. Make sure to combine technological tools with human guidance to help students interpret what the data means, ensure motivation, and create a sense of belonging, thus ensuring socially shared regulation.

Integrate SRL assessment to reinforce learning. Providing students feedback on their SRL development requires assessment of SRL. Moreover, while formative feedback is powerful, students are not only driven by intrinsic motivation, but also summative assessment. Appropriate assessment strategies and instruments for SRL should be developed. Combine easily accessible assessment tools such as self-assessment rubrics, progress checklists, or short reflective prompts, that help students evaluate their own learning processes; with targeted summative assessment preferably connecting SRL to authentic learning tasks.

References

ABET. (2024). Criteria for accrediting engineering programs, 2025-2026. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2025-2026/

Agrawal, A. K., & Harrington-Hurd, S. (2016). Preparing next generation graduates for a global engineering workforce: Insights from tomorrow's engineers. Journal of Engineering Education Transformations, 29(4), 5–12. https://doi.org/10.16920/jeet/2016/v0i0/85428

Atwa, S., Gauci-Mansour, V. J., Thomson, R., & Hegazi, I. (2019). Team-based and case-based learning: a hybrid pedagogy model enhancing students' academic performance and experiences at first-year tertiary level. The Australian Educational Researcher, 46(1), 93–112. https://doi.org/10.1007/s13384-018-0282-y

Baars, M., Zafar, F., Hrehovcsik, M., De Jongh, E., & Paas, F. (2022). Ace your self-study: A mobile application to support self-regulated learning. Frontiers in Psychology, 13, Article 793042. https://doi.org/10.3389/fpsyg.2022.793042

Banihashem, S. K., Farrokhnia, M., Badali, M., & Noroozi, O. (2022). The impacts of constructivist learning design and learning analytics on students' engagement and self-regulation. Innovations in Education and Teaching International, 59(4), 442–452. https://doi.org/10.1080/14703297.2021.1890634

Boekaerts, M. (2011). Emotions, emotion regulation, and self-regulation of learning: Center for the study of learning and instruction, Leiden University, The Netherlands, and KU Leuven. In D. H. Schunk & J. A. Greene, (Eds.), Handbook of self-regulation of learning and performance (pp. 422–439). Routledge.

Butler, D. L., & Winne, P. H. (1995). Feedback and self-regulated learning: A theoretical synthesis. Review of Educational Research, 65(3), 245–281. https://doi.org/10.3102/00346543065003245

Cerezo, R., Esteban, M., Vallejo, G., Sanchez-Santillan, M., & Nuñez, J. C. (2020). Differential efficacy of an intelligent tutoring system for university students: a case study with learning disabilities. Sustainability, 12(21), Article 9184. https://doi.org/10.3390/su12219184

Chu, S. T., Hwang, G. J., Chien, S. Y., & Chang, S. C. (2023). Incorporating teacher intelligence into digital games: An expert system-guided self-regulated learning approach to promoting EFL students' performance in digital gaming contexts. British Journal of Educational Technology, 54(2), 534–553.
https://doi.org/10.1111/bjet.13260

Cimer, A., Odabaşı, S., & Vekli, G. S. (2013). How does reflection help teachers become more effective? Journal of Educational Research, 1(4), 133–149.

Contreras Soto, Y., Oportus Torres, R., Sanhueza Campos, C., & Maluenda Albornoz, J. (2023). Developing self-regulation in English pedagogy students with a focus on the oral ability during the COVID-19 pandemic. Lenguas Modernas, 61, 283–306.

Conway, D. L., Chang, D. A., & Jackson, J. L. (2022). I don't think that means what you think it means: Why precision in lifelong learning terminology matters to medical education. Medical Teacher, 44(7), 702–706.
https://doi.org/10.1080/0142159X.2022.2055456

Daradoumis, T., Marquès Puig, J. M., Arguedas, M., & Calvet Liñan, L. (2021). A distributed systems laboratory that helps students accomplish their assignments through self-regulation of behavior. Educational Technology Research and Development, 69(2), 1077–1099. https://www.jstor.org/stable/27285757

ENAEE. (2021). EUR-ACE Framework Standards and Guidelines. https://www.enaee.eu/wp-content/uploads/2022/03/EAFSG-04112021-English-1-1.pdf

Fabriz, S., Dignath-van Ewijk, C., Poarch, G., & Büttner, G. (2014). Fostering self-monitoring of university students by means of a standardized learning journal — a longitudinal study with process analyses. European Journal of Psychology of Education, 29(2), 239–255. https://www.jstor.org/stable/43551152

Fernández-Martín, F. D., Arco-Tirado, J. L., & Hervás-Torres, M. (2022). The impact of a peer-tutoring program to improve self-regulated learning. Anales de Psicología/Annals of Psychology, 38(1), 110–118. https://doi.org/10.6018/analesps

Hadwin, A. F., Järvelä, S., & Miller, M. (2011). Self-regulated, co-regulated, and socially shared regulation of learning. In D. H. Schunk & J. A. Greene (Eds.), Handbook of self-regulation of learning and performance (pp. 65–84). Taylor & Francis.

Hernández-de-Menéndez, M., Vallejo Guevara, A., Tudón Martínez, J. C., Hernández Alcántara, D., & Morales-Menendez, R. (2019). Active learning in engineering education. A review of fundamentals, best practices and experiences. International Journal on Interactive Design and Manufacturing, 13(3), 909–922. https://doi.org/10.1007/s12008-019-00557-8

Kori, K., Pedaste, M., Leijen, Ä., & Mäeots, M. (2014). Supporting reflection in technology-enhanced learning. Educational Research Review, 11, 45–55. https://doi.org/10.15658/rev.electron.educ.pedagog17.09010109

Lee, H. Y., Chen, P. H., Wang, W. S., Huang, Y. M., & Wu, T. T. (2024). Empowering ChatGPT with guidance mechanism in blended learning: Effect of self-regulated learning, higher-order thinking skills, and knowledge construction. International Journal of Educational Technology in Higher Education, 21(1), Article 16. https://doi.org/10.1186/s41239-024-00447-4

Nguyen, L. T., & Ikeda, M. (2015). The effects of ePortfolio-based learning model on student self-regulated learning. Active Learning in Higher Education, 16(3), 197–209.

Ortiz Alvarado, N., Quintanilla Domínguez, C., Ayala Gaytan, E., & Del Castillo de la Fuente, E. (2024). Development and validation of the multidimensional mindset scale: Growth and fixed mindsets. International Journal of Consumer Studies, 48(3), Article e13054. https://doi.org/10.1111/ijcs.13054

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. Frontiers in Psychology, 8, Article 422. https://doi.org/10.3389/fpsyg.2017.00422.

Reeves, T. D., & Stich, A. E. (2011). Tackling suboptimal bachelor's degree completion rates through training in self-regulated learning (SRL). Innovative Higher Education, 36(1), 3–17.

Ruijten-Dodoiu, P., Valencia, A., & Bravo, E. (2024). Intended learning outcomes on process level in an engineering course with knowledge-based learning outcomes. In

Proceedings of the 52nd Annual Conference of SEFI, Lausanne, Switzerland. https://doi.org/10.5281/zenodo.14256901

Saadati, Z., Zeki, C. P., & Vatankhah Barenji, R. (2023). On the development of blockchain-based learning management system as a metacognitive tool to support self-regulation learning in online higher education. Interactive Learning Environments, 31(5), 3148–3171. https://doi.org/10.1080/10494820.2021.1920429

Sauchelli, I., Heath, G., Richardson, A., Lewis, S., & Lim, L. A. (2024). You've got mail: A technology-mediated feedback strategy to support self-regulated learning in first-year university students. Student Success, 15(1), 11–21. https://doi.org/10.5204/ssj.2825

Schunk, D. H., & Zimmerman, B. J. (2007). Influencing children’s self-efficacy and self-regulation of reading and writing through modeling. Reading & Writing Quarterly, 23(1), 7-25. https://doi.org/10.1080/10573560600837578

Turns, J., Sattler, B., Yasuhara, K., Borgford-Parnell, J., & Atman, C. J. (2014). Integrating reflection into engineering education. In 2014 ASEE Annual Conference & Exposition. https://peer.asee.org/20668

Tuyaerts, S., De Laet, T., Van den Broeck, L., & Langie, G. (2025a). A systematic literature review on self-regulated learning interventions in higher education. [Under review].

Tuyaerts, S., De Laet, T., Van den Broeck, L., & Langie, G. (2025b). Lifelong learning competencies for engineers: a Delphi study with an industry panel. European Journal of Engineering Education, 50(5), 1010–1032. https://doi.org/10.1080/03043797.2025.2500474

Van den Broeck, L., Beagon, U., Craps, S., Coppens, K., Hanssens, J., and Langie, G. (2024a). Learn to learn for life — how can faculty staff support the development of students’ lifelong learning competencies? A systematic literature review. European Journal of Engineering Education, 49(6), 1488–1508. https://doi.org/10.1080/03043797.2024.2416393

Van den Broeck, L., De Laet, T., Dujardin, R., Tuyaerts, S., & Langie, G. (2024). Unveiling the competencies at the core of lifelong learning: A systematic literature review. Educational Research Review, 45, Article 100646. https://doi.org/10.1016/j.edurev.2024.100646

Zhang, R., Zou, D., & Cheng, G. (2024). Self-regulated digital game-based vocabulary learning: Motivation, application of self-regulated learning strategies, EFL vocabulary knowledge development, and their interplay. Computer Assisted Language Learning, 38(8), 1-43. https://doi.org/10.1080/09588221.2024.2344555

Zimmerman, B. J., & A. R. Moylan. (2009). Self-regulation: Where metacognition and motivation intersect. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), Handbook of metacognition in education (pp. 299–315). Routledge.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. Theory into Practice 41(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2

AI statement

During the preparation of this work, the authors used Microsoft Copilot in order to improve language and readability. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

Contributor statement

Conceptualisation	Shan Tuyaerts, Lynn Van den Broeck, Tinne De Laet
Writing - original draft	Shan Tuyaerts, Vicent Rutagangibwa, Peter Ruijten-Dodoiu, Tinne De Laet
Writing - reviewing and editing	Shan Tuyaerts, Vicent Rutagangibwa, Peter Ruijten-Dodoiu, Lynn Van den Broeck, Tinne De Laet