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Self-Efficacy and Metacognition for Digital Literacy toward Self-Regulated Learning in Higher Education

M. S. SUMBAWATI, T. WRAHATNOLO, R. HARIMURTI

ABSTRACT

Introduction. The problem and the aim of the study. Students' low ability to manage their learning independently, including weak metacognition, self-efficacy, and self-regulated learning (SRL) skills, results in a lack of learning independence, poor problem-solving skills, and a mismatch between graduates and their fields of study. Therefore, it's important as implement a student-centered learning model that is structurally measurable through metacognition, SE, and SRL indicators, in order to analyze the model's suitability to empirical data in the field.

Research methods. This study used a quantitative correlational research design with an explanatory approach to identify the influence of metacognition and self-efficacy variables on self-regulated learning (SRL) of students at the Faculty of Engineering, Unesa. The data collection process is carried out by three standardized questionnaires validated by experts using a Likert scale consisting of 5 points, and PLS-SEM (Partial Least Squares Structural Equation Modeling) as a statistical technique for analysis. Testing of the measurement model through confirmatory factor analysis (CFA) and structural model analysis was carried out as a two-stage multilevel analysis process with the aim of adjusting the theoretical model based on empirical findings. Instrument validation included the preparation of grids, writing test items, trials, and item analysis. PLS-SEM used in testing strength of the connection between the constructs studied and the overall suitability of the model.

Results. The analysis results showed that the SE, metacognition, and SRL measurement models fit the data, with all items statistically significant. The vicarious experience dimension in SE had the lowest loading factor (0.573), indicating students' weak confidence in learning from others' experiences. Conversely, more than 70% of students demonstrated high SRL, with a focus on mastering professional skills and openness in discussions. SE and metacognition were shown to have a significant influence on SRL, particularly in planning, monitoring, and organizing learning strategies.

Conclusion. This study found that self-efficacy and metacognition significantly influence students' self-regulated learning (SRL) processes. Students with strong SRL tend to be more proactive, able to face academic challenges, and use student-centered learning strategies. High self-efficacy fosters self-confidence and psychological resilience, while metacognitive skills help students choose strategies, solve problems, think critically, and make informed learning decisions. This positively impacts timely study completion and professional readiness. Therefore, engineering and technology educators need to implement pedagogical approaches that encourage open, reflective, and design-based learning to strengthen students' self-confidence and learning independence.

KEYWORDS

higher education, metacognition, self-efficacy, self-regulated learning, structural model, digital literacy

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INTRODUCTION

Industrial revolution 4.0 accompanied by the development of society 5.0, society will always be involved in digital-based information related to information-based technology, technological activities, network logic, flexible technology, and integrated systems [1; 2]. This is influenced by the current rise of globalization and unlimited services in various sectors. This development certainly has an impact on the process and all sectors of life. The era of technology adoption is an era where technology is used on a large scale in all human activities [3]. This is related to the implementation and planning of sustainable development with information technology systems. Limitations in the use of technology have both negative and positive impacts depending on its use.

The rapid advancement of digital technology is transforming every aspect of modern life, from digitalization and virtual transactions to the management of digital assets and data. With many easy accessibilities, the connection between countries can be attained without conservative blockades [4]. Disturbing conservative blockades are becoming more manageable due to the use of increasingly advanced technology. However, this situation may raise societal impacts, such as when people become increasingly reliant on internet access, reducing their in-person communications.

Interpersonal social impact is one of the consequences of increasing reliance on internet access. Interpersonal social impact is the influence that occurs in the relationships between individuals and others in their social circle [5]. This relates to interactions and reciprocal relationships within society. This impact reflects how social interactions influence behavior, emotions, and the way a person thinks or acts toward others [6]. Consequently, mutual respect and strong interpersonal bonds decrease. For instance, nowadays, teamwork that emphasizes collaboration, in-person communication, and personal familiarity is mostly undertaken virtually through various online platforms.

Another impact is the stability of education in keeping up with technological developments. Education is required to adopt digital technology in line with current developments [7]. Of course, the use of media and learning models in 21st-century education is deemed mandatory efforts to integrate the use of technological developments. This becomes a problem if there is an uneven distribution of technology use by teachers and students within educational units. Differences in suggestions and the use of innovative learning are highlighted. In addition, the fast-paced changes also impact current education. Students feel more anxious and insecure due to the uncertain fluidity of job vacancies, technology shifts, and social instability. Digital literacy goes beyond merely using technology. It encompasses the profound ability to understand and use information from digital technology. This includes not only using technology, but also creating and interpreting digital content [8]. The ability to solve problems and the capacity to adapt to technological changes are essential competencies in this field [9].

The reality that is happening now, while societal changes increase, education remains stagnant. As a result, the new curriculum becomes outdated even before it is implemented. International research has found that the digital skills of young people in several countries are not evenly distributed [11; 12]. Even in education, students' digital skills remain low [13; 14]. Furthermore, technological collaboration within educational institutions is also crucial. Students are required to possess the skills to produce collaborative performance to achieve learning goals.

Collaborative skills are currently needed because the current situation requires a positive response so that students can achieve learning goals in line with the development of this technology. To respond to this uncertain situation, as an important skill with independent mastery where Self-Regulated Learning (SRL) is a critical ability to facilitate managing quality in the student learning process. Self-Regulated Learning (SRL) is an learning independence process that allows students to consciously regulate their feelings, thinking dynamics, and actions to obtain academic and personal goals [15; 16]. SRL includes the ability to actively plan, monitor, and evaluate learning strategies, which are influenced by personal, environmental, and behavioral factors. In technology-integrated educational units, SRL can be optimized through the use of digital media, online learning platforms, and interactive learning tools that support student independence.

The role of teachers in providing relevant emotional, instructional, and technological support is crucial to fostering students' self-efficacy and positive emotions, enabling them to manage their learning process independently and adaptively. Technology integration not only expands access to

information but also strengthens students' ability to control their learning strategies according to individual needs. For example, students can manage independently their learning materials and times for succeeding in academic performance and future collaborative work environment [17]. Moreover, SRL takes a space to help students regulate their cognition, motivation, and behavior, assisting in achieving learning goals [18]. This assistance is indeed vital as a cornerstone for academic achievement and professional growth.

SRL involves continuous self-monitoring and adaptation to adjust students' thoughts, motivations, and actions in connection with their efforts to perform better for each learning objective [19]. Through SRL, students try to achieve plans, monitor and evaluate the dynamic process of strategies in independent learning, providing direct experience of self-controlled success or failure. Successful experiences in organizing and completing learning tasks independently will increase students' self-efficacy, as they feel capable of actively and purposefully addressing challenges.

Self-efficacy (SE) is a person's level of confidence in their ability to achieve set targets and goals [20; 21]. The benefits of Self-Regulated Learning (SRL) are highly correlated with development SE (self-confidence in the ability to complete a task), because both reinforce each other in the independent learning process [22]. To support SRL, teachers become an important stakeholder as their expertise affects how students develop their desired competences. They can model strategic thinking by providing structured guidance to enable their students to internalize SRL processes. For example, they can help students move from teacher-centered learning to self-directed learning by applying metacognitive strategies.

Metacognitive strategies are techniques or approaches that help students become aware of, monitor, and regulate their own thinking processes while learning [23; 24]. These strategies enable students to become active and independent learners because they focus not only on the content of the lesson but also on how they learn. They can also equip their students with the ability to set learning goals, monitor learning accelerations, and adapt appropriate learning strategies independently. Cyclical model is needed in conceiving the aforementioned abilities through three keys, namely planning, action, and evaluation [25]. Each key correlates with one another to create a dynamic feedback loop that can enhance students' learning efficacy. Furthermore, SRL development depends on various factors such as self-efficacy, metacognition, motivation, and persistence, which can be nurtured through a supportive learning environment. Metacognitive strategies support self-development through increased Self-efficacy (SE).

Self-efficacy (SE) in metacognitive strategies to ensureindividual's belief in personal skills to complete actions that have the potential to achieve certain expectations [26]. This belief can impact on students' persistence in coping with challenges. Students with high SE perform better in classroom learning activities [27]. There are several subskills that build up the belief, such as emotional support and positive emotions. Strong SE can improve self-control and confidence in handling various tasks or assignments [21; 28]. For example, students with high SE have more strategic learning paths and effective ways of coping with school tasks [29]. Moreover, students' high SE correlates with better problem-solving skills and self-directed learning. This suggests that considering students' SE may foster proactive learning habits and promote good academic achievement [30].

Metacognitive strategies in SLR enable students' SE to increase. This SLR strategy can be used in a student-centered learning model [31]. The student-centered learning model is a learning approach in which students become active subjects in the learning process, not just recipients of information from the teacher [32]. In this model, the teacher's role is more as a facilitator or guide, while students are given the freedom to explore, ask questions, and develop their own knowledge and skills. This model makes students more independent and proactive in participating in learning.

SRL is relevant to be applied within student-centered teaching, such as inquiry-based, problem-solving, and project-based learning. SRL integrated in those teaching models may cultivate students' metacognitive skills, teamwork, collaboration, and technological skills, which align with the 21st-century education [33]. Metacognition, or familiarly known as "thinking about thinking", reflects awareness and regulation of student's cognitive activities within the learning process [34], It is very important to elevate students' ability in setting effective learning strategies, monitoring the learning progress, and assessing their performance [35]. Moreover, it can improve the quality

of students' essays, enhance higher-order cognitive skills, and enforce students' active participation [35]. Moreover, it can improve the quality of students' essays, enhance higher-order cognitive skills, and enforce students' active participation [36].

Based on the expectations and problems that have been described, this research has the aim of results from the implementation of learning through the measurement model of metacognition, Self-Efficacy (SE), and Self-Regulated Learning (SRL) in student-centered learning. The results of this implementation can analyze the findings in the structural model of Self-Regulated Learning fit with empirical data obtained in the field. These findings can be a study of the application of innovative learning as an effort to determine the correlation between learning with the approach of metacognition, Self-Efficacy (SE), and Self-Regulated Learning (SRL).

MATERIALS AND METHODS

Types of research

This study employed a quantitative correlational research design. A quantitative correlational research design aims to analyze the identification of the size of the relationship (correlation) of two or more research variables [37; 38]. An explanatory approach, which uses survey or ex post facto research methods, is used to examine how events unfold over a specific period of time and to determine whether they have an impact on other events. Researchers collected data through questionnaires and analyzed them statistically to describe the influence of dependent variables on independent variables or to test research hypotheses related to previous research results [40]. This study used a causal or predictive correlational method, which describes the relationship between variables or research constructs.

The main focus in this quantitative research is to provide a statistical description through numerical data of the results of the relationship between the metacognition measurement variables, Self-Efficacy (SE) and Self-Regulated Learning (SRL), so that it can be used as a basis for decision making, intervention planning, or further experimental research [38]. The study examined three key variables: self-regulated learning (SRL) as the dependent variable, with self-efficacy (SE) and metacognition serving as independent variables. This research was carried out in several activity steps which were grouped into three main stages, namely preliminary studies, development and validation of research instruments and development of measurement models.

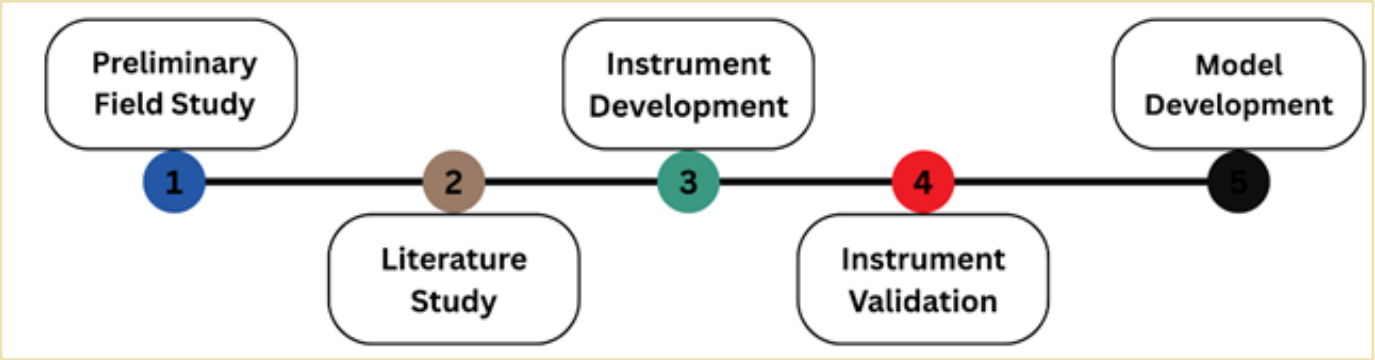

Figure 1 Research flow

In the preliminary study stage, it consists of several activities, namely a field study aimed at obtaining data on the number of FT Unesa students who were active in the even semester of the 2023/2024 academic year with consideration of students entering the sixth semester (2021 intake). The next activity is a literature study to examine and study theories related to SRL, metacognition, and self-efficacy.

Research Population and Sample

The undergraduate students enrolled in Electrical Engineering Education and Information Technology Education programs at Universitas Negeri Surabaya, Indonesia as a target population. Using G*Power software for power analysis, we determined a required sample size of 252 participants, who were subsequently selected through simple random sampling procedures. Sampling in this study was conducted using purposive sampling techniques. Judgment sampling is another term, is to deliberately select participants because they have the same characteristics [40]. who have several similar characteristics, namely students of the Electrical Engineering Education (PTE) and Information Technology Education (PTI) study programs at the Faculty of Engineering, Unesa, who have completed their sixth semester. Additionally, we conducted pilot testing with 36 participants to ensure instrument reliability and validity.

Research Instrument

The data collection process in research activities is a very important activity. In exploratory research, the results of data collection are used to draw generalizations and conclusions by creating descriptions to explore matters related to the research problem. The focus of this research problem is to determine the influence of metacognition and self-efficacy variables on the self-regulated learning variable of Faculty of Engineering Unesa students. Therefore, the data collected in this study is related to the focus of the problem.

Data collection was conducted using three validated questionnaires: The SRL, SE, and metacognition questionnaires. All instruments utilized a 5-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"). Prior to administration, the questionnaires underwent rigorous content validation through evaluation by three subject matter experts. Validation is included in the research instrument development stage, which consists of:

1. Establishing measuring instrument specifications including variables, sub-variables, indicators and grids;
2. Writing the questionnaire;
3. Reviewing the questionnaire;
4. Conducting a pilot test;
5. Analyzing the questionnaire; and
6. Assembling and labeling the instrument.

The questions in the questionnaire are in the form of a rating scale. In general, the development of this instrument includes: objectives, grids, measurement scales, and the number of items. The second step is to compile a grid of non-test instruments in the form of a matrix table of instrument specifications including dimensions, sub-dimensions, item numbers, and the number of instrument items. The instrument used in measuring the variables of this study uses a Likert scale. Writing items from research constructs also uses two types of statements, namely favorable and unfavorable statements. Positive statements express an attitude of agreement and support for the construct, according to the Likert scale used [41].

The number of self-regulated learning variable items consists of 25 items, with dimensions (1) Task analysis consisting of 8 items, (2) Learning factor consisting of 9 items, and (3) Cognitive factor consisting of 8 items.

The self-efficacy variable consists of 18 items. There are unfavorable statements that indicate disagreement and disapproval of the construct, namely items 7 and 10.

The number of Metacognition variable items consists of 22 items, with dimensions (1) Planning consisting of 6 items, (2) Monitoring 5 items, and (3) Regulation as many as 5 items, and (4) Evaluation as many as 6 items. The results of the analysis of the validation of the research instrument from the three variables were obtained as follows.

Table 1

Self-regulated learning questionnaire grid

No	Academic Dimension	Sub dimensions	Item number	Amount
1	Task analysis	Goal setting mlah	1, 2, 3, 4	4
		Strategic planning	5, 6, 7, 8	4
2	Learning Factor	Proactive effort to learn	9, 10, 11, 12, 13	5
		Monitor progress and evaluate goal achievement	14, 15, 16, 17	4
3	Cognitive Factor	Selective attention, rehearsal, elaboration, and structuring	18, 19, 20, 21	4
		Learning motivation patterns	22, 23, 24, 25	4
	Total			25

Table 2

Self-efficacy dimension grid

No	Dimension	Item Number	Amount
1	Mastery experience	1, 2, 3, 4, 5	5
2	Vicarious experience	6, 7, 8, 9	4
3	Social persuasion	10, 11, 12, 13	4
4	Emotional state	14, 15, 16, 17, 18	5
	Total		18

Table 3

Metacognition questionnaire grid

No	Academic Dimension	Sub dimensions	Item number	Amount
1	Planning	Understand how the task will be carried out	1, 2, 3	3
		Identify potential problems	4, 5, 6	3
2	Monitoring	Able to determine the correct concept	7, 8, 9	3
		Aware and knowing how one learns	10, 11	2
3	Regulation	Able to change the rules	12, 13, 14	3
		Self-reflection about what has been processed	15, 16	2
4	Evaluation	Evaluate thought processes	17, 18, 19	3
		Controlling cognitive activity	20, 21, 22	3
	Total			22

Table 4

Percentage results and instrument reliability

Instrument	Validation (%)	Reliability
Self-Regulated Learning	91	.971
Self-Efficacy	89.1	.898
Metacognition	92.9	.853

All instruments used were tested valid in terms of the accuracy and precision of the scales in carrying out their scoring functions. Reliability values obtained from the Cronbach Alpha values of the SRL, SE, and metacognition questionnaires were .917, .898, and .853, respectively. This showed that all instruments were valid, although three SE items and two metacognition instrument items were discarded due to their low correlated-item scores.

Data Analysis Procedures

In the analysis procedure, quantitative data processing techniques used PLS-SEM (Structural Equation Model-Partial Least Squares) [42]. The study employed a two-stage structural equation modeling (SEM) approach comprising measurement model development and structural model analysis. First, evaluation of model measurements to validate the connections between observed indicators and their corresponding latent constructs. Next, filtering the hypothetical map paths between constructs is done to analyze the structural model. The analysis was conducted using PLS-SEM, a robust multivariate technique that assessed both the goodness-of-fit between empirical data and theoretical models and the strength of relationships between latent and manifest variables. This approach enabled simultaneous assessment of path coefficient significance and overall model fit to the field data.

The measurement model analysis was tested using confirmatory factor analysis (CFA). The structural model in this study describes the relationship pattern of all research variables, namely Self-efficacy and Metacognition, to Self-Regulated Learning. The established structural model was tested using confirmatory factor analysis techniques. The purpose of testing is to determine the fit of the data to the model used. The causal or predictive relationships between external and internal variables illustrate the structural model mapped by the researcher. The external variables consist of two: Self-efficacy and Metacognition. The internal variable is Self-Regulated Learning.

Data analysis used SPSS version 26.0 and SEM-PLS. SEM-PLS is a statistical program for structural equation modeling, a form of multivariate data analysis that can test the goodness-of-fit between research data and the hypothesized model [43; 44]. SEM-PLS can be used to test relationships and determine the strength of the relationship between latent and manifest variables. It also examines the significance of the relationships between variables and the fit of the hypothesized model compared to field data.

LITERATURE REVIEW

Self-Regulated Learning

Self-regulated learning (SRL) is defined as the autonomy and control demonstrated by each student as they supervise, guide, and organize their actions toward specific learning goals [45]. Self-regulation relates to processes such as thinking, taking action, behaving, and engaging in meaningful activities. Thoughts that arise from the processing of feelings and actions of students always refer to self-regulation to achieve their respective goals systematically and in an oriented manner. Several prior studies have demonstrated that self-regulated learning (SRL) can boost students' autonomy in controlling their learning strategies. As an essential competence, SRL can help students achieve their learning and professional goals.

For teachers, improving students' SRL can be a prioritized aspect in early education through many efforts, such as equipping students with tools or media to succeed in the learning process [46]. State that strong SRL serves as a key factor of academic and personal advancement. In coping with the SRL exploration. Investigate the factors that can encourage or hinder students' SRL, of which the results show personal traits to support from instructors, peers, and family [47]. Identifying reciprocal correlations between positive self-efficacy, emotional support, and supportive emotions [48]. SRL, in this case, has garnered considerable interest among teachers [49]. Particularly, SRL is vital to support students in managing, redirecting, and regulating their learning processes [50]. In addition, SRL, defined by Bandura, posits that individuals are influenced by personal, environmental, and behavioral traits [47]. SRL is a self-directed process where students can improve their cognitive

skills, resulting in an efficacious academic increase [51]. According to Zimmerman, SRL refers to an individual's learning ability that controls their thinking, feeling, and action to perceive goals [25].

Student Center Learning

Student-Centered Learning (SCL) is an educational approach that places students as the primary subjects in the learning process. In Student-Centered Learning, teachers act as facilitators and guides for student activities, allowing students to be more proactive in implementing learning, from discovering to analyzing results independently [32; 52]. SCL focus active student involvement in the learning process, such as by means discussion, collaboration, problem-solving, and the use of projects or case studies relevant to real life. The aim is for students to be able to obtain construct knowledge independently, develop critical thinking skills, and take responsibility for their own learning process.

Student independence in a student-centered approach provides an opportunity to develop responsibility for their own learning process. Therefore, the benefits of Student-Centered Learning (SCL) primarily increase student motivation and engagement because they feel more in control of their learning. Furthermore, SCL also helps students develop various 21st-century skills such as communication, collaboration, creativity, and critical thinking [52; 53]. SCL accommodates differences in student learning styles and encourages more meaningful and contextual learning. In this way, students not only understand the subject matter, but are also able to apply it in real life situations.

The relationship between Student Centered Learning (SCL) and Self-Regulated Learning (SRL) emphasize the active role of students independently in the teaching and learning process [54]. This lies in the focus of student learning independence. SCL creates a learning environment that allows students to actively participate, make decisions, and engage in meaningful learning activities. In the concept of interactive learning with a two-way relationship between teachers and students, such as group discussions, problem solving, and the use of learning media are means to stimulate students' self-regulation processes (Development of independent learning and thinking). Through collaborative and contextual learning experiences, students are given space to plan, monitor, and evaluate their learning strategies independently, which is the core of SRL.

The collaboration between SRL and SCL supports the development of independent learning by giving students full control over the process and access to their own learning strategies. When students are directly involved in learning decision-making and given the freedom to manage their time, choose their approach, and evaluate their learning outcomes, they are more motivated to develop self-regulation skills [52]. In the SRL model approach, as explained by researchers as previously, combining personal, environmental, and behavioral factors in a unified, directed learning process is very influential in increasing student independence [24; 25]. Therefore, SCL not only serves as a platform for the growth of SRL, but also strengthens students' independence and intrinsic motivation through interactive learning that is oriented towards each student's needs.

Self-Efficacy

The phenomenon of higher education has made independent students move beyond parental supervision. Even though the students demonstrate good maturity, autonomy, and self-regulation, the higher education environment often presents significant emotional and academic challenges. The perceived real life in higher education often involves stress, burnout, and dissatisfaction. This situation forces students to develop resilience, maintain diligence, enthusiasm, and confidence. Success is interfered by self-efficacy, academic preparedness, and adaptive behaviors [55].

(SE) Self-efficacy is related to academic success through its important role in determining students' adaptive behavior. SE effectively predicts students' confidence in their academic abilities. This belief serves as the basis for sustaining learning motivation, emotional states, and personal accomplishment throughout the learning activities [21]. Kubrusly et al. [54] show that higher levels of SE can let individuals achieve their goals effectively. Another instance is a study, which results on the fact that both academic and SE positively influence SRL in e-learning landscape [57]. SE is a powerful construct that can determine human behaviors, for instance, from athletic performance to

academic success. Thus, SE develops individual's confidence progressively and its level tend to rise over time with several highlighted procedures [58].

SE plays a key role in how much effort students put into their work, how long they stick with difficult tasks, and how well they bounce back from academic setbacks. Since prior studies show this strong connection, teachers have a vital part to play in building students' SE through thoughtful lesson design. To boost students' confidence about their skills, teachers should build learning experiences that: (1) keep them engaged with creative and meaningful content, (2) break down skills into manageable steps to form desired learning competence, and (3) provide opportunities for success that gradually strengthen their belief in their skills.

Here are 4 self-efficacy indicators that can be used to measure an individual's belief in their abilities, especially in an academic context:

1. Confidence in Solving Tasks and Problems

Describes the extent to which students feel capable of successfully completing academic tasks, including challenging or complex ones.

2. Persistence in the Face of Adversity

Demonstrates a student's ability to keep trying and not give up easily when facing obstacles or failures in the learning process.

3. Emotional Regulation in Academic Situations

Reflects a student's ability to manage stress, anxiety, or emotional pressure while studying or facing exams, thereby maintaining focus and motivation.

4. Expectations for Future Success

Indicates a student's level of optimism about future academic achievement based on their confidence in their current abilities.

Not all students feel they have sufficient self-efficacy in learning. Therefore, it is necessary to increase self-efficacy by providing gradual and meaningful success experiences for students. The design of activities and assignments is adjusted gradually in an effort to give students an experience of real achievement and build self-confidence. Furthermore, environmental influences, including social support such as positive encouragement from teachers, peers, and parents, are also important in strengthening students' belief in their abilities. Providing constructive feedback and facilitating effective learning strategies such as planning, monitoring, reflection, and evaluation can foster self-regulation and face academic challenges with greater optimism. With this approach, students' self-efficacy can develop sustainably and measurably toward the goal of achieving their academic goals.

Metacognition

Another key element in SRL is metacognition, which becomes essential in portraying how well students understand and manage their thinking when accomplishing learning tasks. Metacognition is crucial for determining learning effectiveness because it enables students to plan strategies, monitor, control, and evaluate their learning. Metacognition can also be said to be an effort to reflect, understand, and control one's cognitive abilities and aspects [59]. The metacognitive process is a learner's self-regulated planning, self-regulation, self-teaching, and self-evaluation at various stages during the learning process.

Metacognition refers to the knowledge and regulation of one's cognitive processes, which is considered a crucial component of creative thinking [60]. Furthermore, it is explained that creative thinking can be considered a metacognitive process that combines individual cognitive knowledge and creative outcomes. Many studies report the beneficial effects of metacognition on students, namely improving learning or developing self-regulation [61]. Researchers have shown that learning failure, resulting from students' inability to regulate and control their cognitive activity, is influenced by the mobilization of metacognitive collaboration. Therefore, metacognitive support is essential for low-achieving students [62].

This skill is not only knowing facts, but also helps students think more creatively by allowing them to step back, assess their approach, and adjust their strategies as needed [60]. Metacognition works on two levels. First, it involves self-awareness, where students monitor and direct their thinking processes [63]. Second, it helps students choose, apply, and refine the right strategies for different situations. [33] Show the significance of SRL in problem-solving activities or in boosting creative thinking [60; 64]. In short, metacognition is not just a theoretical idea; it is a tool to make learning processes more effective.

Metacognition covers a a compound construct linking cognitive and affective regulation. Its theory and practical benefits have been established across disciplines, such as educational psychology, teacher professional development, and contemporary pedagogy [65]. In technology and engineering education, metacognition plays an important role in helping students cope with complex cognitive demands [66]. In addition, contemporary pedagogy is a modern teaching approach that emphasizes responsive, relevant, and student-centered learning practices in accordance with the needs of the times. It integrates the needs of the latest educational theories, digital technology, ethno-cultural aspects, and 21st-century skills such as critical thinking, collaboration, creativity, and digital literacy. Contemporary pedagogy also emphasizes the active role of students in the educational process, the use of varied learning methods (such as project-based or collaborative learning), and formative and reflective evaluation. This relates to cognitive regulation [60; 66].

Cognitive regulation is an individual's skills to consciously control and manage their thought processes while learning or solving problems [65]. This includes various activities such as planning strategies before learning, monitoring understanding during the learning process, and evaluating the effectiveness of strategies afterward. Cognitive regulation is an important component of metacognition and plays a significant role in increasing learning effectiveness, as it enables students to become a responsible, active and independent learner with a reflective nature.

As a primary component of creative cognition, metacognition involves monitoring and regulating students' thinking skills [63]. The metacognitive strategies studied refer to strategies used during the learning process, all of which require problem solving. Problem solving is an intellectual activity frequently used in everyday life. Students need problem-solving skills to adapt and transfer learning to various situations [67]. Problem-solving skills must be able to be carried out by students to go beyond basic skills and knowledge to implement new technologies. Problem-solving proposes that one of the main skills needed is a higher-order thinking skill that is mandatory for students. Problem-solving is a much-needed engineering skill, but the problem-solving performance of engineering graduates is still low.

Current studies have identified three key mechanisms by which metacognition is operated during creative problem-solving:

1. Self-regulation during representational change,
2. Metacognitive monitoring of solution pathways,
3. Confidence calibration in response generation.

Despite the importance of metacognition, how it facilitates students to think creatively remains underspecified. Empirical evidence demonstrates that self-regulated learning (SRL) enhances metacognitive awareness across diverse learning contexts, thereby promoting the cross-domain transfer of regulatory skills [48]. In applied educational settings, this manifests as students' ability to:

1. Accurately assess their cognitive strengths and limitations, and
2. Strategically deploy this awareness

To optimize learning processes through targeted cognitive resource allocation [61].

Research on SRL has been widely conducted, starting from designing, implementing, and evaluating. Likewise, research related to SE and metacognition has been widely conducted. The correlation between SE, SRL and metacognition provides a specification of the influence between each other.

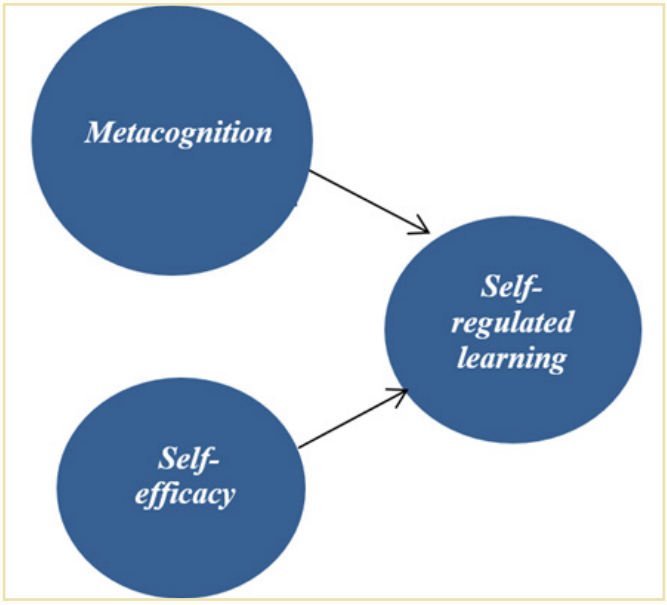

Figure 2 Model of the relationship between SE and metacognition towards SRL

Digital Learning

The crucial use of digital learning refers to the use of digital technology in the educational process, whether online, offline (device-based), or a combination of both (blended learning). This digital learning supports learning flexibility by allowing students to learn anytime and anywhere, and provides personalized space based on each individual's learning needs and pace [2].

Digital learning encourages a more dynamic and interactive approach than conventional methods. With a technological approach, teachers can present a variety of learning media, such as online quizzes, discussion forums, and multimedia presentations to increase student participation [68]. This approach also facilitates ongoing assessment and provides real-time feedback. Furthermore, technology integration encourages the development of students' digital skills [69], which are essential competencies in facing the era of Industry 4.0 and an information-based society.

However, technological accessibility in learning is a major factor in the implementation of digital technology in its integration with current learning (technology-based learning). This relates to digital literacy, which individuals must master before implementing digital learning [70]. Digital literacy is the skills to access, understand, evaluate, create, and implemented information through digital technology effectively, critically, and ethically. This includes proficiency in the use or technical skills needed to implement digital devices (such as computers, smartphones, and the internet), as well as the ability to analyze the validity of information, personal and public privacy, and communicate responsibly.

In the representation of education, digital literacy is a crucial competency because it supports students in independent learning, seeking relevant information, and actively participating in technology-based learning [70]. The extraordinary freedom of access in this modern era greatly supports the implementation of digital literacy [69]. This literacy also includes an understanding of digital ethics; therefore, digital literacy is not only about technical skills but also about shaping students' character so that they become wise and responsible technology users.

Easy device access, stable internet network, and digital literacy support are key requirements for the success of digital learning. Effective implementation must consider the digital divide, both generally and specifically, to optimally utilize devices and learning applications [68]. With proper planning and support, digital technology-based learning can improve the quality of education and create a more inclusive, relevant, and adaptive learning experience for modern developments.

Digital learning provides ample scope for the development of students' Self-Regulated Learning (SRL) and Self-Efficacy (SE), providing them with access to learning independently, flexibly, and

tailored to their individual needs. Through access to various digital resources, students can plan, monitor, and evaluate their own learning process, which is the core of SRL. In this context, success in completing digital tasks or achieving learning targets independently can increase students' confidence in their abilities (SE). Furthermore, interactive features and instant feedback within digital platforms also help strengthen learning motivation, reduce dependence on teachers, and encourage students to be more confident in managing academic challenges independently.

However, there are still few studies that discuss the factors that influence SRL that focus on engineering students with digital literacy, so that they are not only able to develop metacognition for digital literacy and be more confident in solving problems and assignments, but also independent in learning. Given these conditions, this study aims to evaluate the structural model of SRL using empirical data collected in the field. Additionally, this research seeks to examine the impact of SE and metacognition for digital literacy on the SRL of students in engineering education. The originality of this study is that testing the structural model of SRL on Electrical Engineering Education and Information Technology Education students has not been carried out, even though SRL is one of the keys to student success in the world of work.

RESEARCH RESULTS

Measurement Model Analysis

The measurement model aims to determine the influence of manifest variables (indicators) on latent variables. The model fit was assessed to evaluate the correspondence between the hypothesized model and empirical data. Goodness-of-fit indices included the Standardized Root Mean Square Residual (SRMR), with values below 0.08 indicating acceptable fit, and the Normed Fit Index (NFI), where values exceeding 0.9 represented satisfactory model performance. The measurement model evaluation incorporated four key assessments: (1) Convergent validity check, through factor input and Average Variance Extracted (AVE) values; (2) discriminant validity; (3) composite reliability; and (4) AVE analysis. For convergent validity specifically, we established criteria requiring both minimum factor loadings and AVE values to confirm adequate construct representation. See Fig. 3.

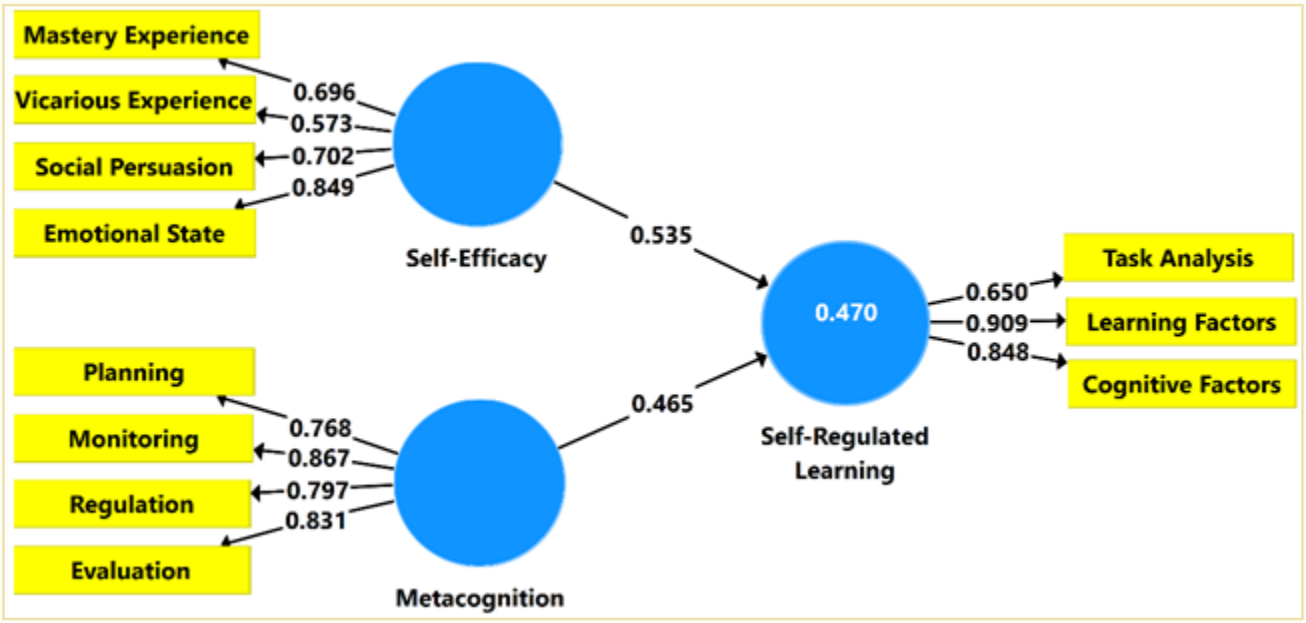

Figure 3 Structural model of self-regulated learning

Table 5 shows the dimensions that measured the variables of SE, metacognition, and SRL, which had high loading factor values, namely > .7. However, some dimensions had low loading factor values of .573 in the vicarious experience dimension, but were still acceptable because > .5 [42]. It could be concluded that CV was accepted.

Table 5

Loading factor, CR, and AVE (N=252)

Variable	Dimension	Loading	Cronbach Alpha	CR	AVE
SE	Mastery Experience	.696	.678	.889	.507
	Vicarious Experience	.573			
	Social Persuasion	.702			
	Emotional State	.849			
Metacognition	Planning	.768	0.835	0.801	0.667
	Monitoring	.867			
	Regulation	.797			
	Evaluation	.831			
SRL	Task Analysis	.650	0.734	0.849	0.656
	Learning Factor	.909			
	Cognitive Factor	.848			

In addition to validity, the reliability of each construct and indicator was also tested. The reliability test was that if the Cronbach's Alpha value and the CR values were > .70, so the research instrument could be said to be reliable [42]. The SE variable had a Cronbach's Alpha value of .678 (not reliable), but the CR reached .889. Other variables, metacognition, and SRL, had Cronbach's Alpha and CR values > .7; therefore, the research instrument was reliable. The numbers in bold belonged to their corresponding loading factor, which was known to be greater than the cross-loading of another construct.

Table 6

Loading factor, CR, and AVE (N=252)

	SE	Metacognition	SRL
Mastery Experience	.696	– .042	.263
Vicarious Experience	.573	– .066	.264
Social Persuasion	.702	– .049	.360
Emotional State	.849	– .035	.487
Planning	– .099	.768	.259
Monitoring	.005	.867	.438
Regulation	– .116	.797	.310
Evaluation	– .033	.831	.360
Task Analysis	.407	.102	.650
Learning Factors	.533	.363	.909
Cognitive Factors	.293	.518	.848

Based on Table 6, which illustrates that the cross-loading value between constructs on the measured variables must be greater than the cross-loading value of constructs from other variables. The bold value was the construct's cross-loading on the measures, known to be greater than the cross-loading of other constructs, so it implied that the discriminant validity was fulfilled. The parameter analysis results showed that the loading factors on all research construct items were statistically significant (> .2). This means that the observed variables were valid indicators of the latent variables of the research constructs. Each variable also exhibited an AVE value exceeding the correlation coefficients between variables. For instance, the SE variable had an AVE of .712, exceeding the correlation values, thereby confirming discriminant validity (see Table 7).

Table 7

AVE value of discriminant validity/fornell-larcker criterion results

	Metacognition	SE	SRL
Metacognition	.817	–	–
SE	– .063	.712	–
SRL	.431	.505	.810
Emotional State	.849	– .035	.487

The basis for making a decision on discriminant validity is that it is met if the AVE value > correlation between latent variables (constructs) [42; 71]. The AVE value is highlighted in green. Each variable has an AVE value > correlation between variables. From these results, it is concluded that discriminant validity is met. As shown in Table 8, the HTMT ratio was less than .90, which means there was no violation of the construct of discriminant validity. Thus, the criteria of the HTMT ratio were met.

Table 8

Heterotrait-monotrait ratio (HTMT)

	Metacognition	SE	SRL
Metacognition			
SE	.119	–	
SRL	.502	.694	
Emotional State	.849	– .035	.487

Structural Model Analysis

The causal or predictive relationship or correlation between exogenous and endogenous variables can be described by a structural model determined by the researcher. The exogenous variables consist of two variables: self-efficacy, consisting of four observed variables, and metacognition, also with four observed variables. The endogenous variable is self-regulated learning, with three observed variables. The evaluation of the structural model aims to test the presence or absence of influence between variables or correlation between constructs. The structural model evaluation served dual purposes: assessing overall model fit and examining hypothesized relationships between constructs.

Using SEM modeling techniques with the partial least squares method (PLS-SEM), we conducted a comprehensive analysis that included: (1) collinearity assessment to ensure discriminant validity, (2) computation of R^2 values to evaluate predictive power, and (3) examination of path coefficients to test directional hypotheses. The path coefficient analysis specifically determined both the statistical significance and directionality of relationships between latent variables, thereby validating the proposed theoretical framework. Meanwhile, path coefficients aim to test the significance of the path coefficient between the measured variable and other variables so that it can be determined whether the relationship between the variables is significant and directional according to the hypothesis [42].

The variance inflation factor (VIF) value was examined to measure collinearity, with a VIF < 3 indicating minimal multicollinearity problems. The analysis revealed VIF values of 1.004 for both self-efficacy (SE) and metacognition as independent variables, confirming that the structural model was free from collinearity problems. Predictive power was evaluated using R^2 values, which quantify the combined influence of independent variables on the dependent variable. Following established interpretation guidelines, R^2 values were categorized as: strong (≥ 0.75), moderate (0.50-0.75), or weak (≤ 0.25) [42; 71]. The obtained R^2 value of 0.470 indicated moderate predictive power of the model.

Furthermore, in order to determine the extent of the independent variable's influence on the dependent variable, the hypothesis test aims to determine the significance of the relationship between latent variables (both independent and dependent) using the estimated path relationship values using the P-Value and t-statistics. Table 9 shows the results of the influence on each variable.

Table 9

Hypothesis testing

	Original Sample	Sample Mean	Standard Deviation	t−statistics	p−values
SE–>SRL	.535	.541	.057	9.402	.000
Metacognition–> SRL	.465	.462	.061	7.665	.000

Table 9 refers to the t−table calculated with df = 249, α = .05, so that the t-table, two-tailed obtained is 1.65. The test criteria used for the model, the relationship between significant variables is p−value < .05 or t count > t table. The effect of SE on SRL, t−statistics of 9.402, and p−value of .000, so it can be inferred that SE affects SRL positively and significantly. If SE increases, SRL increases. The effect of metacognition on SRL obtained t−statistics of 7.665, and p−value of .000, so it can be inferred that metacognition affects SRL positively and significantly. If metacognition increases, then SRL increases.

The final test in the structural model is the Goodness of Fit test. The model fit test is used to understand the model used to determine whether the model fits the data or not. The fit test can be determined by looking at the NFI and SRMR values. The NFI value is between 0-1, the model is said to fit if the NFI value is close to 1, or more than 0.9 is said to be good. A good SRMR value is less than 0.08. The results of the study obtained an NFI value of 0.727 and SRMR of 0.101, indicating that the model is said to fit, so it has a match with the data.

DISCUSSION

Data Conformity with Facts on the Ground

The results of data analysis from the analysis of the measurement model and model structure obtained that the measurement model of all research constructs fit the data, and the results of the parameter analysis showed that the loading factors of all research construct items were statistically significant. Based on the results of the measurement model analysis, it was found that the measurement model of all research constructs was significantly fit, this was generated from the Chi-square value of the data in the field. If examined more deeply from the SE construct in the Table 6 it appears that the dimension of vicarious experience of students is suspected to be weak with a loading factor of 0.573 meaning a lack of individual understanding of their own abilities. Students are reluctant to share information about their learning and the problems they face. Self-efficacy refers to a person's belief in their own abilities that are issued to achieve goals and how much they can survive facing problems or challenges [58; 72]. On the other hand, SE can experience change, over time and through more experience such as formal education, on-the-job training, and continuous professional development [71].

Looking at other conditions, namely self-regulated learning (SRL), it was found that more than 70% of participants in this study showed a high level of attention to mastering professional knowledge and skills, this finding was not solely oriented towards graduation exams. However, their belief in learning the material will have an important role in their future careers (becoming knowledge motivation), and good academic achievement can be achieved through consistent effort and hard work [48; 73]. In addition, the majority of respondents, shown with results of >70% of the population, stated that they did not agree with the statement of reluctance to distribute information regarding learning and problems faced by classmates, as well as conveying their views in group discussions.

Self-Efficacy and Self-Regulated Learning

The findings of this study establish a significant positive relationship between self-efficacy (SE) and self-regulated learning (SRL), consistent with social cognitive theory. Students with stronger SE beliefs demonstrated greater persistence in overcoming academic challenges and higher goal attainment rates, particularly in their ability to manage time, organize tasks, set strategic goals, monitor comprehension, and optimize learning environments. Crucially, the results position SE as a dynamic cognitive mediator rather than a fixed trait, revealing its multifaceted role in influencing learning behaviors. Specifically, SE level had an impact on the complexity of students' goals, students' commitment to attain the goals, and students' expectations of successful performance. These results collectively underscore SE's essential function as a supporting mechanism to shape students' self-regulation in academic contexts [74]. SE is an individual belief in employing controls over difficult demands, echoing self-confidence about their abilities [75].

SRL represents a complex process where students should engage in goal-directed behaviors to attain academic achievement. Several studies indicate that SRL is influenced by SE, metacognitive awareness, personal initiative, task persistence, intrinsic motivation, and adaptive behaviors. Students who perform effective SRL typically show better academic engagement and an increased willingness to take challenges, and lessening their inconfidence. This cyclical process involves continuous monitoring and adjustment of cognitive strategies, motivational states, and behavioral patterns to optimize learning outcomes.

Students with high SE tend to show greater ability to develop and implement effective learning strategies compared to those with lower SE. This difference in engagement happens because self-efficacy (SE) plays a well-known role in motivation and how people regulate their behavior. Teaching methods that get students actively involved in building knowledge, especially hands-on approaches like discovery learning, project-based learning, and problem-based learning, work well for strengthening SE-motivation and SE-learning behavior connections. These interactive approaches help students in three important ways: (1) students learn the material better by actually working with it; (2) students become more accurate at judging their own skills; and (3) students develop smarter study habits that lead to better grades.

Metacognition and Self-Regulated Learning

The present study highlights the significant role of metacognition in facilitating SRL implementation. This finding suggests that instructional integration of metacognitive strategies (e.g., planning, monitoring, and evaluation techniques) can make students develop their awareness and intentional control reflected in their learning behaviors. Importantly, the establishment of learning goals serves as a basis of metacognitive skills used to cultivate SRL competencies. The cyclical nature of SRL manifests as a feedback loop, where students can (1) plan strategic learning strategies, (2) monitor their learning progress, (3) evaluate learning attainments, and (4) regulate efforts adaptively. These results emphasize that teachers who systematically use metacognitive scaffolding in their teaching can significantly advance their students' ability to undertake self-directed learning.

Metacognition, known as thinking about thinking, plays a powerful role in students' learning and mental development [24]. This advanced mental skill may help students solve problems systematically and master complex subjects by permitting others to assess what they know and track their learning progress. Metacognition is thinking about the content and processes of one's cognition. Research shows that metacognition plays a crucial role in most cognitive tasks, from everyday behavior and problem-solving to expert performance [24]. When learning, people monitor what they know and whether it aligns with their desired learning outcomes. The learner's ability to monitor effectively is known as calibration. Students then control their subsequent actions based on their monitoring, and ultimately they self-regulate the process of monitoring and controlling their learning by shaping and adapting their cognitions or behaviors moving forward and planning for future tasks [76].

Research shows that people learn better when they have strong metacognitive abilities and when they can manage their learning effectively. The present study confirms that stronger metacognition leads to better school performance. For instance [77] found that math students with maximum learning efforts may perceive most learning benefits. Thus, it is necessary to boost learning skills

through (1) finding students' motivation, (2) understanding their strengths, and (3) practicing different thinking strategies. Developing these metacognitive skills is key to becoming a more effective self-directed learner.

In addition, students enrolled in Electrical Engineering Education and Information Technology Education programs are prospective teachers who should develop and conceive comprehensive professional competencies, covering instructional planning, pedagogical implementation, evaluative assessment, and emotional-motivational regulation. Effective teaching professionalism requires teachers' ability to navigate pedagogical problems and create complex educational contexts [78]. Moreover, as prospective teachers, they have to cultivate autonomous competencies in strategic planning, progress monitoring, outcome evaluation, and emotional self-regulation. Contemporary studies emphasize that reflective teaching practices incorporating educational technology can enhance students' higher-order thinking skills. Teachers who utilize technology and media to get their students to think critically may help them develop both their critical thinking and reflective thinking skills [79; 80].

Metacognition a multidimensional construct encompassing both cognitive and affective regulatory processes has become increasingly prominent across educational domains, including: teacher preparation programs, professional development initiatives, and technology-enhanced learning environments. This cognitive capability assumes particular significance in technology and engineering education, where the intricate relationship between conceptual understanding and practical application demands heightened metacognitive awareness from both instructors and learners [66]. The complex problem-solving nature of these disciplines requires systematic monitoring of thought processes and continuous adjustment of strategies during both learning and teaching activities.

A well-structured classroom environment that fosters positive emotional and social interactions enables students to optimize their learning by internalizing behavioral expectations and engaging more effectively in academic activities. Such environments enhance students' attentional focus and responsiveness to learning demands, while promoting higher-quality peer interactions. These conditions facilitate the early development of higher-order cognitive skills including analysis, synthesis, and critical argumentation which collectively support emerging metacognitive abilities. Metacognition, defined as the awareness and regulation of one's cognitive processes, empowers students to: (1) self-monitor their learning, (2) strategically deploy cognitive skills, and (3) employ knowledge construction and organizational strategies. Our findings highlight three critical factors for developing metacognitive competence: (a) systematic pedagogical sequencing, (b) explicit teacher guidance, and (c) deliberate practice in cognitive regulation. Together, these elements create the necessary scaffolding for robust metacognitive development in educational settings.

CONCLUSION

This study conveys that self-efficacy and metacognition significantly influence students' self-regulated learning (SRL) processes. Students with strong SRL perform more proactive learning behaviors, including persistent engagement with challenging tasks and effective use of learning strategies. These behaviors are consistent with key constructivist learning approaches student-centered (e.g., inquiry-based, discovery, problem-based, and project-based learning), which simultaneously apply strategic peer collaboration and help-seeking.

Moreover, students with strong self-efficacy demonstrate greater confidence in demanding academic work. They also exhibit enhanced capacity for independent learning. This firm psychological resilience makes the students persist through academic challenges and complete the designated tasks successfully. In addition, metacognitive skills facilitate SRL by enabling students to: (1) select appropriate learning strategies, (2) solve problems effectively, (3) make informed decisions, and (4) engage in critical thinking to achieve learning objectives. The development of students' autonomous learning may complete their studies within suggested timelines and perform better professional work. When students recognize the relevance between their future careers and what they have learned, they will know the use of the learned knowledge as a long-term professional success.

Forthcoming technology and engineering educators can use pedagogical approaches that promote unstructured learning activities, open-ended problem solving, and design-based

projects, interplaying STEM content with reflective teaching. The present study not only identifies key factors affecting the learning outcomes, but it also shows the cognitive and situational constrains encountered by students. These limitations can be effectively mitigated through two primary mechanisms: (1) enhancing students' self-efficacy (SE) beliefs in their capabilities, and (2) developing their capacity to establish clear learning objectives while selecting appropriate strategies for organizing and managing learning tasks.

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