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A Systematized Literature Review on Problem-Solving in STEM Education Exploring the Impact of Task Complexity on Cognitive Factors and Student Engagement

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Abstract

The profound impact of cognitive factors on student's performance while solving complex and ill−structured problems is well recognized. A student's success in problem−solving is finely shaped by task complexity, cognitive factors of goal orientation and the need for cognitive closure, and their level of engagement. For educators in science, technology, engineering, and mathematics (STEM), it is important to understand how task complexity and cognitive factors combine to influence problem−solving processes to prepare STEM students professionally and ensure they are well−equipped to meet the growing needs of the skilled workforce in the industry. In this context, cognitive factors of goal orientation and the need for cognitive closure play a significant role. An extensive body of research has yielded diverse findings and insights and has explored the relationship between task complexity, cognitive factors of goal orientation, and the need for cognitive closure, and their combined impact on student engagement in the context of STEM education. This growing body of research emphasizes the need for a comprehensive synthesis and analysis of existing literature to utilize the wealth of knowledge productively that has developed over time. By analyzing the existing literature comprehensively, this systematized literature review addresses the influence of task complexity on the cognitive factors of goal orientation and the need for cognitive closure and students' engagement during problem−solving in STEM education. Resultant themes central to the research questions are being developed using qualitative data analysis techniques. By synthesizing the existing research, this review sheds light on how the student's cognitive responses are influenced by different levels of task complexity during problem−solving and how the task complexity enhances or hinders student's engagement in STEM education.

Keywords: Engagement, Goal Orientation, Need for Cognitive Closure, problem−solving, STEM, Task Complexity.

Introduction

According to Krajcik [1], there is a shift in science education from simply teaching science ideas to fostering students to figure out processes and problem solutions. STEM education was developed to deal with the challenges of the 21st century and train students to be competitive by improving critical thinking skills and being creative, productive, innovative, and logical. Students can use the knowledge gained while solving problems in everyday life and at the workplace as demanded by industry nowadays. A skillful workforce can foster the country's economic development by enhancing innovation and productivity [2]. The creation of the required workforce is realized through STEM education with an interdisciplinary perspective and its part in training individuals with 21st century skills. Sen *et al*. [3] defined 21st century skills as engineering problem−solving skills, design skills, creativity, digital expertise, and cooperation. Most importantly the growing significance of STEM education in developing problem−solving skills is becoming the focal point of discussion. According to Malçok and Ceylan [4], a significant relationship exists between STEM education and problem−solving skills. The cognitive attributes of goal orientation and the need for cognitive closure shape a student's success in problem−solving in conjunction with their level of engagement. For educators in STEM, it is vital to comprehend how task complexity and cognitive factors combine to influence problem–solving processes to prepare professional STEM students and ensure they are well–equipped to meet the changing demands of the industry.

To investigate the relationship between task complexity, cognitive factors of goal orientation the need for cognitive closure, and their combined impact on student engagement in the setting of STEM education, prior research in the areas of problem–solving , goal orientation, and the need for cognitive closure was explored. This research aligns with the fourth major shift in engineering education related to a broader move towards evidence based practices and scholarship of engagement, contributing valuable insights to address challenges in STEM learning environments [5].

Task Complexity in Problem Solving

While solving a problem the problem solver often adopts their cognitive strategies to the features of the problem statement and the nature of the task [6]. The transition from the initial problem state to the solution state is governed by multiple processes depending on the individual's level of understanding and proficiency, and the "structuredness" of the problem or task [7]. According to Smith [8], problem–solving performance is directly affected by internal (personal attributes) and external factors (nature of the problem). Several studies highlighted the importance of knowledge structure representation of a problem in problem–solving performance [8]-[12]. The problem representation involves the context, the structure (easy or complex), verbal or visual representation, and the typology or kind of the problem. Jonassen [10] differentiated structured and ill–structured tasks regarding their implications in instructional designs. Well–structured problems are tailored to the specific domains and are characterized by a single convergent solution. In contrast, ill–structured problems offer multiple solutions and are usually open–ended.

Goal Orientation

Solving a complex problem demands more than just knowledge; it requires personal creativity and motivation to deal with the challenges and persist until a solution is achieved. Students' goal orientation during problem–solving is linked to the key sources of self [13]. It helps to determine student's varying attitudes and behaviors regarding learning and achievement situations [14], [15]. Although different methods are used to assess goal orientation, research indicates that problem–solving influences goal orientation and can be used to measure it. There are two primary goal orientations agreed upon by the researchers: mastery–approach goal orientation and performance–approach goal orientation [16], [17]. Students with mastery goal orientation are characterized by the desire to master the tasks with interest and intrinsic motivation and gain a deeper understanding of the subject matter. They view challenges and mistakes as growth opportunities and aim to be competent in personal development rather than with a desire to compete with others. While the students with performance–approach goal orientation typically concentrate on exhibiting their abilities in comparison to others and are primarily concerned with the outcome of their efforts.

Need for Cognitive Closure

Students usually experience confusion or difficulty while solving challenging tasks. Engaging with complex tasks is typically seen as beneficial by educators, as the learners ultimately achieve a more profound comprehension of the subject matter. However, the advantage is dependent on how these challenges are approached. The need for cognitive closure is the one factor that can hinder or impede the required engagement to control the inherent uncertainty associated with mastering complex tasks [18], [19]. As articulated by Kruglanski and his colleagues [19], [20], the need for cognitive closure shows a motivated inclination to simplify complex information, actively seek structure, and avoid ambiguity. In psychology, the significant impact of the need for cognitive closure on cognitive processes is associated with problem−solving including how we explore different possible solutions [21], [22]. Kruglanski [23] defined the need for cognitive closure as "desire for a firm answer to a question, any firm answer as compared to confusion and/or ambiguity." The pace of this process varies among individuals, some may form a conclusive opinion promptly with limited information, while others may consistently refrain from making decisions regardless of the available evidence. Students can have various goals while approaching problems but to determine their actual behavior and actions and how they genuinely approach problem−solving, the concept of the need for cognitive closure is important. Sometimes students' stated goals contradict their actions.

Research Questions

This review explores how the structure of a problem specifically in terms of task complexity, influences cognitive factors such as Goal Orientation and Need for Cognitive Closure. By reviewing the available literature, this systematized literature review aims to answer the following research questions:
(1) How does task complexity influence cognitive factors of goal orientation and the need for cognitive closure among students during problem−solving in STEM education?

(2) How does task complexity impact student engagement in STEM education?

Method

To answer the research questions, a systematized literature review was conducted as a structured exploration of the existing literature. The articles were purposefully selected based on the precise inclusion and exclusion criteria. A codebook was developed for documenting the selected articles; for carefully analyzing the objectives, sample characteristics, data collection method, results, implications, and limitations of each study; and for establishing preliminary connections according to our research questions. Their results were synthesized by the systematic thematic synthesis method presented by Booth *et al*. [24] and communicated through a narrative description. Themes were developed through a process of thematic analysis [25].

Search and Selection Criteria

A precise criterion was developed to guide each phase of the literature review, including literature search, selection, and quality aligned with research questions as mentioned in Table 1. Search criteria were developed to ensure that the literature retrieved aligned with the study's designated timeframe (publications between 2003 and 2023) and to focus on four areas: STEM, task complexity, cognitive factors of need for cognitive closure and goal orientation, and cognitive engagement among students. The rationale behind expanding the search to a broader timeframe is to consider significant research from early years and to capture historical trends and changes in the field to ensure that the research considered was aligned with the evolving landscape of STEM education. Then the selection criteria determined which pieces returned by the searches met the inclusion requirements for the synthesis. We have chosen to incorporate literature across secondary and post−secondary education to comprehensively include all relevant scholarly works. This selection is motivated by the recognition that this marks the first literature review on this specific topic within our knowledge.

Table 1. Search and Selection Inclusion Exclusion Criteria

Search Type	Categorization	Explanation
Selection	Document Type	Peer−reviewed Journal Articles & Conference papers.
Quality selection	Empirical research	Empirical research presents clear research questions, design, data collection, analysis method, and findings. (Excluding meta−analyses, reviews, and article summaries)
Search & selection	Publication period	Published between Jan 2003-Dec 2023
Selection	STEM Education	Research on high school, undergraduate, and graduate students (excluding faculty)
Search & selection	Task Complexity AND cognitive factors	Research addressing both task complexity AND cognitive factors provides findings specific to students in education.
Selection	Language	English

Lastly, quality selection criteria were applied to ensure that all studies met our standards for empirical research excluding article summaries, meta−analyses, and reviews. For a comprehensive literature search and selection, the snowballing method based on Wohlin *et al*. [26] work was adopted.

List for Search Terms

The primary categories of search terms that are aligned with research questions are task complexity, cognitive factors, STEM, and cognitive engagement. Below are the sample terms used for each category to facilitate a comprehensive exploration of the literature:

Task Complexity: Task Complexity, Problem Complexity, Complex Tasks, Perceived complexity, problem−solving, Problem−based learning.

Cognitive factors: Need for closure, Cognitive closure, Need for cognitive closure, Decision−making, Goal orientation, Goal setting, Goal achievement.

STEM*:* STEM, Science, Technology, Engineering, Mathematics, Engineer.

Engagement*:* Cognitive engagement, Engagement.

Search Engine Selection

Multiple search databases were used in the process to compile a comprehensive literature dataset and minimize redundant and unproductive searches. Through test searches conducted on EBSCOhost, ERIC, Scopus, and IEEE Xplore to identify the most suitable platform, EBSCOhost yielded the highest number of results with the fewest duplicate results. Hence, the final searches are conducted on the EBSCOhost, IEEE Xplore, and SCOPUS search databases in combination, using search terms or strings.

Building Search Strings

Multiple search strings were built by taking all the possible combinations of search keywords. Each string is made with the union and intersection of the four key concept categories: task complexity, STEM education, cognitive factors (Need for cognitive closure and Goal Orientation), and Engagement. The use of the OR Boolean operator in the search string ensures that any of those terms need to appear in the resulting literature as they serve the same concept. While the AND operator confirms the intersectionality among the three key concepts. Multiple search strings like the ones mentioned below in Table 2, were formed to extract an extensive collection of literature while maintaining the simplicity of search terms.

Coding Table

After applying the inclusion and exclusion criteria on the selected databases and using multiple search strings, EBSCOhost and IEEE Xplore generated 52 and 40 peer–reviewed articles respectively. While the Scopus database yielded 26 relevant articles. In the first step, 118 articles were assessed using their title and abstracts. To make sure that relevant studies were not excluded from the review, we have retained all the studies conducted in different disciplines in the title and abstract assessment. By employing a hybrid coding approach, a codebook was developed using both deductive and inductive coding elements [27].

Table 2. Examples of Search Strings

Sr#	Search Strings	Database
1	("task complexity" OR "complex problem " OR "Complex tasks") AND ("need for cognitive closure" OR "cognitive closure" OR "need for closure" OR "goal orientation" OR "Goal setting" OR "Achievement goal") AND (STEM education OR science OR technology OR engineering OR mathematics)	EBSCOhost (ERIC APA PsycINFO Computer Source Academic Search Ultimate Education Source) IEEE Xplore Scopus
2	("task complexity" OR "complex tasks " OR "Complex problem" OR "Problem–based learning") AND ("need for closure" OR "cognitive closure" OR "Need for cognitive Closure") AND (STEM education OR science OR technology OR engineering OR mathematics)	
3	("task complexity" OR "complex problem " OR "Complex task" OR "Problem–based learning" OR "problem–solving") AND ("engagement" OR "cognitive engagement") AND (STEM education OR science OR technology OR engineering OR mathematics)	
4	("task complexity" OR "complex tasks " OR "Complex problem" OR "Problem–based learning" OR "problem–solving") AND ("Goal Orientation" OR "Goal Setting" OR "Goal Achievement") AND (STEM education or science or technology or engineering or mathematics)	

Initially, the review of articles was based on documenting the study's objectives, results, and outcomes to make the initial connections with the research questions. Then a second review of the data was conducted to document the sample characteristics, study purpose and focus, and research design characteristics of the selected articles. A unified coding table is formed by consolidating the two sets of coding elements, updated periodically when required and treated as a dynamic document. Hence during the initial assessment, 60 articles were excluded as they did not include STEM students as participants. In the second step, the remaining 58 articles were assessed fully for inclusion based on full–text article reading. Out of 58 articles, only 20 studies [28-47] met all the inclusion–exclusion criteria (Table 1) and were selected for review.

The included studies encompass papers with diverse demographics across different regions and disciplines. A major portion of 55% of the total studies belongs to the USA, papers from Europe contribute 30% and Australian research backs 10% of the literature. While papers from other regions collectively contribute 5% of the literature. In terms of discipline, engineering–related studies showcase a key presence with 65%, Mathematics contributes 15% and Science and technology disciplines contribute 20% of the total studies, adding further depth to the diverse academic landscape covered within the review.

Synthesis Method

The systematized literature review synthesis is consistent with the systematic thematic synthesis method discussed by Booth *et al*. [24] to generate new interpretations by the integration of quantitative, qualitative, and mixed–method studies and by using thematic analysis.

Analysis

A thematic analysis is applied to develop the key themes across the array of studies mentioned in the coding table. This approach is adopted from the work of Saldana [25] to extract common ideas and conclusions related to our research questions instead of generating new knowledge although it is possible. This systematized literature review presents key findings by synthesizing the relevant studies mentioned in the coding table aligned with our research questions.

Findings

The analysis of 20 studies included in this synthesis resulted in the three key themes: Shaping goals amid task complexity, Creativity, and Engagement driven by complexity.

Theme 1: Shaping Goals Amid Task Complexity

The literature showed a compelling interaction between task complexity and goal orientation indicating a significant relation between the two but mediated by different factors. This theme is developed to address the first research question keeping in view the factors mentioned in the literature impacting students' goal orientation in complex problem–solving and molding their goals according to the challenges. This reflects the dynamic nature of goal setting, suggesting that students adjust and shape their goals based on challenges presented by the complex problem–solving tasks.

Faber and Benson [28] recruited undergraduate biomedical engineering students to explore their epistemic cognition while solving open–ended complex problems. During the interview, the students were asked about their goals when solving the problem with questions such as: “What was your goal when you first approached this problem?” and “What, if anything, did you hope to gain by solving this problem?”. Eight of the students focused primarily on completing assignments quickly, getting good grades, and trying to align their answers as expected by the instructor. This aligns with the performance–approach orientation as their motivation is driven by competition and recognition. Students described the factors shaping their goals for homework problems including context, level of interest, utility value associated with the task, and perceived expectations of the instructor. Furthermore, personal interest emerged as a key factor in shaping goals, as several students indicated their level of interest in a problem influences their goals in such a way that if they find the topic to be engaging, they will invest extra effort, otherwise they just aim for a passing grade.

The consideration of utility value associated with tasks is another factor that influences the goals they set as mentioned by the previous study as well [29]. When the students perceive that the problem is complex, some of them consider it a chance to explore and deal with the complexities of the task, rather than a hurdle. Instead, the context of the problem, interest, utility, and their beliefs about their instructor's expectations can shift their focus from mastery to work avoidance. Pieschl *et al*. [30] explored how students handle different complex tasks and adjust their goals accordingly by recruiting high school students who attended biology or chemistry classes in six different complex learning tasks. The findings align with the theme as they showcase the adaptability of goal setting based on task complexity. The results showed that students could tell the difference between simple and complex tasks as they made changes to their goals or plans. They dug deeper to analyze the complex tasks in comparison to easy tasks in which they used shallow plans for the analysis. This is also endorsed by Dupeyrat and Mariné [31], performance goals are usually associated with shallow−processing strategies such as rote learning. This shows that students adopt a mastery goal toward complex tasks by analyzing the task deeply instead of showing avoidance.

Similarly, Song and Grabowski [32] investigated the relationship between goal orientation, problem−solving skills, and motivation by employing research on science students. They presented the students with an ill−structured problem in different goal−oriented contexts because they needed to consider multiple factors to find the solution. Results of the study have shown that students who were exposed to a learning−oriented context were more motivated to solve ill−structured problems as compared to the performance−oriented context. Learning−oriented context included the instructional strategies to orient students towards learning−goal orientation by incorporating three contextual factors "(a) task design, (b) distribution of authority and (c) recognition or evaluation of student practices" [32]. This emphasizes the role of contextual factors in shaping goal orientation confirming the theme of adapting goals amid varying complexities.

When the educational environment emphasizes achieving specific outcomes, open−ended learning environments cannot be implemented successfully. According to Song [33], if the stress is on the performance and the evaluation is based on a comparison, students will focus more on performance goals. In another study by Canfield and Zastavker [34], the key stumbling blocks of grades and perceived course usefulness are highlighted for encouraging mastery goal orientation. They emphasize the context of the learner's autonomy while solving open−ended problems similarly as discussed above by Song and Grabowski [32] of the distribution of authority for developing the mastery goal orientation. This approach will position the instructor as a facilitator in the classroom and give students autonomy for their learning. This study examined the effects of the first−year mechanical engineering curriculum on the student's goal orientation and explained the struggle that students had while transitioning from highly structured problems of high school to open−ended problem−solving projects resulting in the reluctance from the instructors to implement the pedagogy. However, some students feel overwhelmed in the open−ended learning environment while others feel frustration as: *"I like to be challenged to a point where I'm not stressed out and frustrated to the point where I can't be happy or have fun with it, but it's not so easy that it becomes unimportant to me"* (Student, Interview 1, 4/18/08). Another student mentioned that *"If I choose a really easy one then I won't really learn anything. If I choose the hard one then it's going to be way too hard. [...] I already have a lot of other stuff to do, so I want to take the hard one [and] if I had more time I wouldn't mind taking it*" (Student, Interview 2, 11/20/07).

This reflects that student's goal orientation in open–ended problem solving is also shaped by the consideration of factors of grades and perceived usefulness of the course.

Tasks containing fewer details are engaging for some students while frustrating for others. Lawanto *et al*. [35] explored the relationship between student's task understanding and goal orientation while engaged in problem–solving activities in an Engineering thermodynamics course. Results have shown that as the semester progressed and the task became complex, student's focus on mastering the content increased rather than just getting good grades. Students had an easier time understanding explicit tasks but struggled with implicit ones. Explicit tasks encompass clear information without ambiguity while implicit tasks hold the details beyond the description of the problem including valuable resources required for problem–solving. Students encountered difficulty in making connections to the concepts that instructors felt were obvious. Montero and Gonzalez [36] also discussed the complexities associated with open–ended complex problems and their ill–structuredness. They presented an experience of the structured problem–based approach to teaching in an engineering course. Emphasis was made on enhancing the complexity of the task gradually to keep the students engaged. Liu and Liu [37] discussed the influence of goal orientation on problem–solving performance in a simulation–based learning environment and found that student's preconceptions about the complexity of the problem influenced their problem–solving strategies. Participants may not have found problems to be engaging that were designed to be ill–structured, complex, open–ended, and real–life based.

Theme 2: Creativity: Interplay between Task Complexity and Need for Cognitive Closure

Students can have various goals while approaching problems but to determine their actual behavior and actions, and how they truly approach problem–solving , the concept of the need for cognitive closure is important. This theme is developed to address the part of the first research question, examining the influence of task complexity on the necessity of cognitive closure during problem–solving . The impact of task complexity on the need for cognitive closure is mostly associated with task completion timing and creativity across the literature. While investigating the open–ended homework problem–solving approach of engineering students, Faber and Benson [28] asked a student about her goals she said: "*Well, I kind of had in my head that the stress–strain for older bones would be less, so I just wanted to make sure I was right and find it in the paper.*" The primary focus of the student here was finishing the problem quickly as she spent just 15 minutes on it. Her strong urge for immediate closure appears to be having a high need for closure. She didn't consider the alternatives and embraced her beliefs quickly. Her beliefs underscore the importance of the need for cognitive closure for measuring the constructs of closed–mindedness and discomforts with ambiguity.

Faber and Benson [28] captured the student's motivation while encountering complexities in a problem using the scale of cognitive closure and emphasized that an individual's need for cognitive closure affects how students solve complex problems. Results of the study made by Huang *et al*. [38] are also aligned with the fact that high need for cognitive closure individuals tend to exhibit a seizing approach to get the issue resolved quickly as they investigated how online students process complex and ill–structured problems and the relation between deep or surface approaches of the learners with the need for closure.
The literature revealed that the need for cognitive closure is associated with the creativity of the student while solving complex problems. Ma and Rapee [39] explored the connection

between task complexity and the need for cognitive closure in terms of creativity and mathematical problem–solving. Students were presented with both simple and complex problems. The findings indicate that students exhibiting a high need for cognitive closure excelled in handling complex tasks but performed worse in terms of creativity, aligned with the previous research made by Prabhu *et al*. [40]. Wojtowicz and Wojtowicz [41] determined the relationship between the need for cognitive closure and the level of creative behavior while solving complex designs. They employed architecture students to investigate a relationship and revealed that the increased level of cognitive closure is associated with decreased creativity and a less generative attitude.

Another study was conducted by Bourgeois-Bougrine *et al*. [42] aiming to assess the effectiveness of the creativity tools in a conceptual design challenge by analyzing the strategies used by the students at each stage of the creative process. The results suggest that creative students used different techniques to sustain through all the tasks exhibiting a low need for cognitive closure while students with low creativity exhibited convergent thinking and saturation and tried to complete the project as early as possible with a lack of motivation and commitment exhibiting a high need for cognitive closure. The synthesis across these studies underscores a consistent pattern: as task complexity increases, students tend to exhibit a high need for cognitive closure, and trade–off creativity for an instant problem–solving approach, while students tend to exhibit a low need for cognitive closure sustained through the complex tasks and consider multiple solutions leading to creativity, showcasing the complex dynamics between task complexity, cognitive closure, and creativity trade–offs.

Theme 3: Engagement Driven by Task Complexity

This theme is formulated to address the second research question, investigating how task complexity affects student engagement in STEM education. Across the literature, the impact of task complexity on student engagement varied in two ways. Some studies have shown that task complexity enhances engagement and skill development while others agreed that task complexity hinders student engagement.

In engineering problem–solving, student's task interpretation skills are affected when engaged in solving a complex problem. In routine teaching, any problem in the textbook can be structured as boring or exciting. If the problem is complex but engaging, students may find an ingenious solution one day or get failed in the next day. The more important thing is whether the student is excited or ready for a challenging task or not. The literature revealed that complex or open–ended tasks enhance engagement, trigger motivation, and catalyze skill development. Dringenberg and Purzer [43] investigated the experience of first–year engineering students working on ill–structured problems and found that students involved in the ill–structured problem ambiguity by recognizing and accepting it. Embracing ambiguity is connected to broader positive encounters with open–ended problems, encompassing student's recognition of the enhanced flexibility afforded by the chances to interact with such problem scenarios. According to research made by Montero and Gonzalez [36], open–ended complex problems are best suited for skill development and if a meaningful percentage is assigned to the problems in assessments, student engagement can be improved. They also suggested that complexity needs to be heightened gradually so that students remain engaged.

Jollands *et al*. [44] examined student engagement in a project–based course of Sustainable Engineering, a core course for chemical engineers that contributes to the development of capabilities including problem–solving and decision–making through the integration of real−life based problems and compared them with the students engaged in traditional lecture−based classrooms. Problem−based learning (PBL) is mainly concerned with students learning what they need to solve a problem while in traditional classrooms students learn what the teacher thinks they should learn. The result of the study is aligned with the theme showing that student engagement was higher in PBL classrooms than in traditional ones. Similarly, Yadav *et al*. [45] explored the engagement of electrical engineering students in complex and ill−structured problems as PBL intervention by pre−post test design and compared it with a lecture−based approach. The open−ended responses of the students reflected that they were more comfortable with the traditional method and learned more than PBL but besides that, they underlined the importance of developing their problem−solving skills and engagement through the applicability of the skills using PBL.

Zhou *et al*. [46] discussed the complex task in terms of an opportunity for creative thinking and engagement among engineering education students in a PBL environment. This helps in building extensive knowledge in solving real−life problems that require deep engagement [38], [46]. McNeill *et al*. [47] interviewed engineering students after a problem−solving session to identify their perception of problem−solving. Problems were complex and open−ended and complex and close−ended. They described that open−ended problems are complex, but some liked the flexibility due to the freedom of choosing the solution. They emphasized that dealing with real−world problems gave them the confidence to deal with complexity and ambiguity.

Besides engagement, motivation, and skill development, several studies in the literature emphasized that some factors hinder student engagement while solving complex problems. This means task complexity does not consistently lead to increased student engagement. As mentioned by Canfield and Zastavker [34], some students feel autonomous while others feel frustrated in solving open−ended problems in the absence of guidance or clear instructions. But in group work, they engage through a divide−and−conquer approach. This implies that the complex problem when divided into parts in groups allows students to leverage each other's strengths fostering a collaborative problem−solving process. Similarly, Lawanto *et al*. [35] discussed that students struggled with implicit tasks as compared to explicit ones because of a lack of clarity and details. This highlights the potential challenges faced by the students in the absence of effective instructional strategies required to enhance student's skills in solving complex problems. Some students merely perform well in complex tasks with the primary focus on getting good grades. This needs to be focused while designing complex tasks to minimize the fear of failure and to encourage problem−solving abilities. Although engineering students feel stressed when they are first introduced to ill−structured problems, they try to focus more on passing the exam rather than the problem−solving process, but this can be catered to by introducing some adjustments as discussed by Canfield and Zastavker [34]. They emphasized the importance of student's evaluation based on understanding and how well students comprehend the concepts rather than solely measuring their adherence to the task and rote memorization. In addition to these factors, personal interest plays a crucial role in influencing student's engagement in complex tasks. Personal interest acts as a motivating factor that can contribute to increased engagement and investment in the learning or problem−solving process [28]. Hence, we cannot say that complex tasks always enhance engagement and skill development but sometimes some factors hinder the performance of students and need to be addressed while designing complex problems.

Discussion

In addressing the research question, analysis reveals that the student's goal orientation while solving complex tasks varies and is mediated by the factors of context, interest, and utility of the problem, along with individual beliefs and instructor expectations [28], [29], [34]. Besides these mediating factors, Mastery goal orientation was dominated while solving complex tasks, and fostering deeper comprehension, creativity, and problem–solving skills. Students used shallow processing strategies toward easy tasks while embracing mastery goals in complex tasks. The motivation of students towards ill–structured problems was supported by the goal orientation for sustainability in a problem–solving environment. Most high school students struggle during their transition to undergraduate studies, particularly when shifting from solving structured problems to handling open–ended problems in projects. This is also why sometimes instructors are reluctant to apply this pedagogy. Some students get frustrated with the complexity and are just solving the problem keeping in mind to get good grades and are more inclined to performance goal orientation with the fear of failure. Montero and Gonzalez [36] presented a structured problem–based approach and suggested that the complexity of the problem needs to be increased gradually to keep the students engaged. Similarly, Lawanto *et al*. [35] discussed that task structure plays an important role in student's engagement in problem–solving. Sometimes the instructor's perception about the complexity of the task differs from the student's view and students struggle to make connections with the information that is not given. The task complexity should strike a balance, encouraging students to actively engage with the solution while also providing opportunities for weaker students to stay involved and seek alternative solutions [48].

The other cognitive factor of the need for cognitive closure has its importance in understanding the behavior of students toward problem–solving. In literature, the need for cognitive closure is mostly associated with the creativity of the students [39], [41]. Results have shown that students exhibit a high need for cognitive closure, least creativity, convergent thinking, and closed–mindedness while solving complex problems. The students with a low need for cognitive closure are open–minded, and creative, and look for different possible solutions to reach the solution. Synthesis results encouraged the structuredness of the complex task in a way that can encourage the problem–solving abilities of the students rather than their avoidance behavior due to frustration. Some students lean towards the traditional way of learning rather than problem–based learning, which includes ill–structured and real life problem–based tasks, because of the complexity involved in solving problems. They were simultaneously motivated that their problem–solving skills were enhanced in a problem–based learning environment. Open–ended problems can foster problem–solving skill development if they are structured in a way that students can break the problem into chunks for understanding, can be able to make connections with the prior knowledge, are related to specific domains, and are understandable for both weaker and bright students. Teachers can foster this process by acting as facilitators in the learning process by providing learners autonomy as discussed by Song and Grabowski [32]. They can also encourage the process of complex problem–solving by organizing students in groups so that if the problem is complex, divide and conquer approach can assist them in navigating through the intricacies of the problem [32], [34].

Limitation

While this systematized review offers foundational work related to the relationship between cognitive factors, task complexity, and engagement in problem–solving, it is important to acknowledge the limitations associated with the robustness and applicability of the results. The focus on STEM education might limit its generalizability to other disciplines because the nature of tasks, problem−solving approaches, and cognitive engagement vary across different fields of study. There is also a constraint of prevalent emphasis on Western perspectives of the included studies. To address this issue, cultural inclusivity should be introduced in the future to enhance the external validity of the research findings, avoid cultural bias, and make them more relevant for a broader educational context worldwide. There is also a limitation that lies in grouping the studies from high school and undergraduate and graduate levels together. In the future, the effects of task complexity within distinct contexts of high school problem−solving scenarios and problem−solving at undergraduate and graduate levels could be investigated separately to provide clear insights within each domain.

Conclusion

This review offers a thorough insight into the student's cognitive factors influenced by different levels of task complexity during problem−solving in STEM education. The results have shown that both goal orientation and the need for cognitive closure are strongly influenced by the complex nature of the task. Task complexity plays a vital role in shaping intelligence beliefs influenced by various contextual and personal factors, leading students to adopt mastery goals, while less complex tasks may lead to work avoidance and a reluctance to engage deeply in the task. Studies suggested that complex problems tend to focus on completing the problem quickly having a more decisive approach towards problem−solving resulting in a high need for cognitive closure. This approach may affect the student's willingness to engage with complex or ambiguous tasks as they avoid being involved in multiple solutions and tend to prefer quick solutions. Comparatively, the students who solve the problem with a more creative and constructive approach having the aim of gaining a deeper understanding exhibit a low need for cognitive closure and are more productive. Most of the studies have shown increased engagement and problem−solving skill development in solving complex tasks but some studies have also presented the factors hindering student's engagement. This reflects that task complexity can either boost or impede the student's engagement in the problem−solving process. Hence, we can say that in complex problem−solving, student's performance goal orientation, high need for cognitive closure, and decreased engagement can obstruct their problem−solving skill development.

Implications

This literature review offers a significant contribution to the effective pedagogical strategies that educators can implement to optimize cognitive factors and engagement of students in complex problem−solving. To foster student engagement, mastery goal orientation, and creativity, an instructor can consider not only the task's structure but also the student's beliefs, perceptions, and interests. This involves offering support, guidance, contextual relevance, utility value, and encouraging collaboration with peers. These considerations contribute to a learning environment where students are actively involved, motivated to achieve mastery, and empowered to express their creativity. Accordingly, teachers can design the tasks thoughtfully by providing challenges appropriately to enhance the problem−solving abilities of the students. Consequently, the STEM students with their improved problem−solving abilities will be prepared professionally according to the growing needs of the industry.

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