

REVIEW OF THE LITERATURE IN LEARNING SUPPORT IN STEM EDUCATION AT THE HIGHER EDUCATION LEVEL

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Abstract

Science, Technology, Engineering, and Mathematics (STEM) education has emerged as an important area of focus within the higher education system due to its potential ability to contribute to technological innovation, scientific advancement, and subsequent economic growth in society. However, higher education learners in STEM areas of study often face unforeseen challenges throughout their academic journey, requiring the presence of reliable and effective learning support structures. This review article explores, collects and presents the extensive literature on learning support in STEM education in a coherent manner, examining different frameworks, strategies, and tools used to design learning support in the STEM field of studies to enhance learning outcomes. The article explores several aspects of learning support research covering cognitive, socio-cultural, and technological factors influencing learning support and discusses the best practices for improving student engagement, retention, and performance. The review also identifies gaps in current research and delves into future directions for improving learning support in STEM education. In addition to that, the article discusses the role of assessment techniques and discusses some case studies in understanding the efficacy of learning support interventions.

Keywords: *STEM Education, learning support, learning outcomes, higher education.*

1. Introduction

STEM education plays an important role in getting students ready with the skills necessary to thrive in an increasingly innovation-led and technology-driven world. Governments, educators, and policymakers globally have recognized the importance of STEM education in solving critical societal challenges, such as sustainability, healthcare, and digital transformation. Due to the challenging and cognitively demanding nature of these subject areas, students in STEM disciplines often struggle with complex content and abstract concepts. These challenges associated with effective student learning have generated a growing interest in understanding how to provide appropriate learning support to STEM students. STEM fields are characterized by high cognitive loads, frequent use of abstract reasoning, and the requirement of procedural fluency in mathematics and computational thinking (National Research Council, 2011). This combination often leads to high dropout rates and lower retention in STEM majors compared to other disciplines. The current body of research highlights a range of approaches and interventions aimed at better student support subsequently improving student outcomes. This article offers a comprehensive review of the literature on learning support in STEM education at higher education levels, with a focus on the evolution of educational frameworks, the role of technology, and the development of strategies that address the complex and diverse needs of learners. We will examine both theoretical perspectives and practical applications in a bid to identify the most effective methods for enhancing student success in STEM fields.

2. Conceptual frameworks in learning support for STEM

2.1. Cognitive learning theories

One of the key areas of research in learning support for STEM education is grounded in cognitive learning theories. These theories explain how students process information, solve problems, and acquire knowledge. Cognitive load theory (Sweller, 1988) is one of the important pieces of work in understanding why students struggle with complex STEM topics and subject areas. It argues that the human brain has a limited capacity for processing new information, and when students are overwhelmed by high levels of

cognitive demands, their ability to learn is reduced significantly. This theory is particularly applicable in fields like physics, mathematics, and engineering, where students must simultaneously learn content knowledge and problem-solving procedures. Cognitive load theory therefore discusses the need for instructional methods that manage the cognitive load, thereby enabling a deeper understanding of the topics and subject areas and learning. In addition to cognitive load theory, other key models such as Piaget's theory of cognitive development and Vygotsky's social constructivism have significantly shaped the design of learning support mechanisms in STEM education.

2.1.1. Piaget's theory of cognitive development. Piaget's Theory of Cognitive Development talks about student's construction of knowledge through experiences and interactions with their environment. Piaget argued that cognitive development occurs in stages, and students' ability to grasp abstract scientific and mathematical concepts depends on their developmental stage (Piaget, 1972). In the context of STEM education, this theory suggests that students benefit from active learning environments where they can experiment, explore, and apply theoretical concepts. Problem-based learning (PBL) and inquiry-based learning (IBL) are frequently cited as instructional strategies aligned with Piagetian principles. These approaches emphasize hands-on, experiential learning where students are encouraged to solve real-world problems collaboratively. Research by Savery (2006) emphasizes that PBL fosters critical thinking and deeper understanding in STEM fields by encouraging students to tackle complex problems, often without a clear solution pathway, therefore mirroring the work of scientific and engineering innovation processes.

2.1.2. Vygotsky's social constructivism. Vygotsky's Social Constructivism, on the other hand, highlights the importance of social interaction and cultural context in learning, irrespective of the field of study or topics. According to Vygotsky (1978), learning is a collaborative process, and cognitive development is largely influenced by interaction with learning facilitators or even the more knowledgeable peers. The concept of the "zone of proximal development" (ZPD) is particularly relevant for learning support in the STEM field of study, as it emphasizes the value of scaffolding—providing support structures that guide students through difficult topics until they can achieve an independent understanding of it (Wood et al., 1976). Scaffolding of learning can take various forms in STEM education, including the use of visual aids, step-by-step instructions, practical demonstrations and guided questioning techniques. Peer-assisted learning (PAL) and cooperative learning methods provide natural forms of scaffolding by allowing students to benefit from the collective knowledge and problem-solving skills of their peers. The ZPD framework supports the idea that students can solve more complex problems with guidance than they could on their own, making it a powerful tool in STEM education where problem-solving skills are of utmost importance.

2.2. Socio-cultural approaches

While cognition-related theories have dominated much of the research on learning support in research across the learning support in all fields of study or topics including STEM, socio-cultural approaches have also made significant contributions. These approaches particularly stress on the role of social context, identity, and culture in shaping the learning experience, particularly in STEM education.

2.2.1. Situated learning theory. Situated Learning Theory, introduced by Lave and Wenger (1991), argues that learning is fundamentally a social phenomenon and takes place best when students participate in learning practices within a community. In STEM education, this theory has led to the development of learning environments that reflect the practices of real-world problem solving simulating the works of scientists, engineers, and mathematicians. Laboratory work, and collaborative projects in controlled environments to find solutions to real-world type problems (but may be at a much smaller scale suitable for learners) are examples of situated learning opportunities allowing students to engage in developing critical thinking and problem-solving in meaningful ways, particularly so in STEM-related fields. Wenger's concept of "communities of practice" further supports the idea that students develop expertise by engaging in shared learning activities with others who have similar interests and goals (Wenger, 1998). Communities of practice are common in STEM fields of study, where students may participate in research groups, attend academic conferences, or collaborate on large-scale engineering projects. These communities foster a sense of identity and belonging, which is important for the retention of students in STEM fields.

2.2.2. Culturally responsive pedagogy. Culturally Responsive Pedagogy (CRP) plays a crucial role in learning support for the STEM field of studies. It emphasizes the need for academics to consider the cultural backgrounds and life experiences of the prospective students when designing curriculum, learning materials and instructional strategies (Gay, 2010). In many cases, the STEM field of study has been critiqued for being culturally neutral or even exclusionary, failing to reflect the diverse backgrounds of its students. Research has shown that STEM fields of study that incorporate culturally relevant examples and

applications can increase engagement and motivation, particularly for underrepresented minorities. For example, using real-world problems drawn from students' communities or cultural contexts can help to gain clarity on STEM subjects and make them more acceptable and accessible to diverse learners. The integration of culturally relevant pedagogy into the delivery of the STEM field of study is particularly important in addressing the underrepresentation of racial and ethnic minorities in STEM fields. This helps create a more inclusive and encouraging learning environment.

2.3. Motivation and self-regulation

Another important area of research on student support in the STEM field of education focuses on motivational and self-regulatory aspects of learning in STEM. Theories such as Self-Determination Theory and Goal Orientation Theory provide insights into how students' motivation can be supported to enhance their learning outcomes.

2.3.1. Self-determination theory. Self-determination theory, developed by Deci and Ryan (1985), argues that students are more likely to succeed when their basic psychological needs for self-determination, competence, and relatedness are met. In the STEM field of study, giving students choice and control over their learning can foster their internal motivation. Project-based learning, for instance, allows students to pursue their own interests within the broader context of STEM curricula, promoting a sense of autonomy. Additionally, research by Deci, Vallerand, Pelletier, and Ryan (1991) suggests that the perception of competence in the STEM field of study is strongly correlated with persistence and success in these fields. This finding underscores the importance of creating learning environments where students can experience success, receive constructive feedback, and develop a sense of competence over the material.

2.3.2. Goal orientation theory. Goal Orientation Theory distinguishes between mastery and performance orientations, where mastery-oriented students focus on learning and understanding, on the other hand, performance-oriented students focus on demonstrating competence relative to others. Studies have demonstrated that mastery orientation leads to deeper engagement and better long-term learning outcomes in STEM, whereas performance orientation may lead to anxiety, avoidance behaviors, and disengagement (Ames & Archer, 1988). Mastery-oriented environments encourage students to see mistakes as learning opportunities rather than failures, fostering a growth mindset (Dweck, 2006). This is particularly relevant in STEM fields, where problem-solving often involves trial and error, and where persistence in the face of failure is a key determinant of success.

3. Technological innovations in learning support for STEM

The emergence of innovative educational technologies has also significantly transformed learning support in STEM education. Technological innovations such as intelligent tutoring systems, virtual laboratories, and online learning platforms have enhanced access to personalized learning experiences, offering students tools to navigate the complexities of STEM disciplines. These innovations not only supplement traditional teaching methods but also cater to a wide range of learning preferences and cognitive styles.

3.1. Intelligent Tutoring Systems (ITS)

Intelligent Tutoring Systems (ITS) have become an important form of learning support in STEM education. These systems use artificial intelligence to provide custom instruction and feedback to students. Unlike traditional educational software, ITS adapt to individual learners' learning patterns, offering appropriate explanations, hints, and problem sets that respond to their specific learning needs. Research has demonstrated that ITS can significantly improve student outcomes by adapting content to individual learning requirements, and providing immediate feedback (VanLehn, 2011).

The Cognitive Tutor system focuses on mathematics instruction and has been shown to improve students' algebra proficiency by adapting to their problem-solving approaches and providing personalized feedback (Pane et al., 2014). The system assesses students' responses in real-time and offers hints or alternative explanations when they struggle, therefore serving as a digital one-on-one tutor. Although intelligent tutoring systems have proven effective, it is important to recognize that these systems are most successful when integrated into a well thought and suitable instructional framework.

3.2. Virtual and augmented reality in STEM learning

Virtual and augmented reality (VR and AR) technologies have opened new opportunities for experiential learning in the STEM field of education. VR allows students to explore immersive environments where they can interact with abstract concepts in ways that would be difficult or impossible in a traditional classroom. For example, students can use VR to simulate chemical reactions, explore the structure of molecules, or visualize complex engineering systems. Research by De Jong, Linn, and Zacharia (2013) discusses the potential of virtual laboratories to enhance students' conceptual understanding of science through a risk-free environment for experimentation. Similarly, AR can be used to overlay digital information onto the physical world, offering interactive, real-time data that enhances understanding.

4. Gaps in the literature and future directions

Despite the significant progress made in understanding and implementing learning support in STEM education, several gaps remain in the literature. First, there is a need for more longitudinal studies that examine the long-term impact of learning support interventions. While many studies focus on short-term outcomes, such as test scores or immediate course performance, it is important to assess how these interventions influence students' career trajectories and professional success in STEM fields. Second, more research is needed on the intersection of technology and pedagogy in STEM education. While technological tools such as ITS, VR, and AR have shown great promise, research must continue to explore how technology can complement and enhance human instruction rather than replace it. Finally, the impact of learning support interventions on students' socio-emotional development, such as confidence, resilience, and identity formation, is an area that warrants further exploration. These factors play a critical role in students' long-term success in STEM fields, particularly for underrepresented groups.

5. Conclusion

Learning support is an essential component of STEM education, providing students with the tools, resources, and strategies they need to navigate the complexities of STEM disciplines. The literature offers valuable insights into a range of effective learning support strategies, from cognitive and socio-cultural approaches to technological innovations and targeted support for underrepresented groups. However, there is still much work to be done in terms of expanding research on the long-term effectiveness of these interventions and developing more inclusive and equitable learning support systems. As STEM education continues to evolve, the integration of these support mechanisms will be crucial for preparing students to succeed in a rapidly changing world.

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