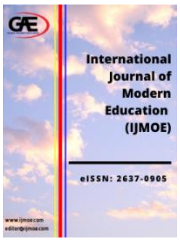
International Journal of Modern Education
IJMOE
EISSN: 2637-0905

Volume 6 Issue 23 (December 2024) PP. 455-469
DOI: 10.35631/IJMOE.623031



INTERNATIONAL JOURNAL OF MODERN EDUCATION (IJMOE)
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THE NEEDS OF COMPETENCY ASSESSMENT IN STEM EDUCATION: A SYSTEMATIC LITERATURE REVIEW

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Article Info:

Article history:
Received date: 24.10.2024
Revised date: 10.11.2024
Accepted date: 12.12.2024
Published date: 23.12.2024

To cite this document:

Ng, C. H., & Adnan, M. (2024). The Needs Of Competency Assessment In Stem Education: A Systematic Literature Review. *International Journal of Modern Education, 6* (23), 455-469.

DOI: 10.35631/IJMOE.623031

Abstract:

STEM (Science, Technology, Engineering, and Mathematics) education has become a major educational program in most developing countries to provide talented workforces for economic development. In developing future workforces, the need for competency assessments in STEM education has become a major concern, and the way of implementing the assessment has also been discussed for over a decade. Competency assessment in STEM education is essential to ensuring students possess the knowledge, STEM skills, and attitudes in the STEM field. In this paper, a systematic literature review used the PRISMA framework to evaluate the need for competency assessment, synthesize current research on assessment in STEM education, and identify the prevalent assessment methods, challenges, and best practices. Following the PRISMA guidelines, a review across Scopus, Emerald, Science Direct, and Springer Link databases was screened based on the predefined inclusion and exclusion criteria. The findings found that most indicated mono-disciplined standardized assessments, project-based assessments, 21st-century skills, and interest in the mono-disciplinary. This finding highlights the urgent need for a competency assessment model in STEM education by improving the effectiveness of competency assessment to enhance STEM education outcomes.

Keywords:

STEM Education, Competency Assessment, STEM Skills, PRISMA

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Introduction

The world's education is developing rapidly, especially in STEM (Science, Technology, Engineering, and Mathematics). STEM education has become a major educational development project in many developing countries to improve the country's competitiveness and provide talented workforces for economic development. As mentioned by Gao et al. (2020), the future workforce needs adequate STEM knowledge and skills to face future challenges. Countries such as the United States, China, United Kingdom (UK), Finland, Malaysia, and others have launched policies to propose the importance of STEM education literacy cultivation and workforces on STEM talents. Such as STEM 2026: A Vision for Innovation in STEM Education in United States (Tanenbaum, 2016), China STEM Education 2029 Action Plan (Zhang & Chen, 2023), Science and Innovation Investment Framework 2004–2014 (HM Treasury, 2004), and a subsequent STEM strategy (2014–2024) in UK (Hoyle, 2016), LUMA Programme in Finland (LUMA, 2013) and Malaysia Education Blueprint 2013-2025 in Malaysia (MOE,2013). In 2023, with the approval of the established UNESCO International Institute for STEM Education (IISTEM) in China to promote STEM education globally (UNESCO, 2023). IISTEM recognized the development of STEM education is important to achieving sustainable development goals (SDGs), solving pressing world challenges, and spurring socio-economic development (UNESCO, 2023). Competency in the content of the SDGs refers to the combination of knowledge, skills, and attitudes. The competency encompassing talented workforces will sustain the developing country (Kelly & Knowles, 2016).

This paper aims to evaluate the issues and needs for competency assessment in STEM education by conducting a systematic literature review (SLR) through the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 guidelines. This study synthesizes current research on competency assessment in STEM education and identifies the prevalent assessment methods, challenges, and best practices. Therefore, in this paper, all the relevant literature on competency assessment in STEM education will be reviewed and analyzed.

Study Issues

STEM education is an interdisciplinary approach that compasses knowledge and skills in the four fields of STEM. However, the assessment in STEM education is mostly a traditional or monodisciplinary approach, focusing on increasing interest in STEM and attitudes towards STEM (Ng & Mazlini, 2022). The interdisciplinary assessment in STEM education should be implemented and assessed to ensure that the future workforce has the competency that is needed for country development. Competency assessment in STEM education is essential to ensure students possess the knowledge, and STEM skills, and have good attitudes in the STEM field.

In this study, the papers for competency assessment in STEM education are reviewed to answer three research questions: 1) What are the differences between traditional assessment and competency assessments in STEM education? 2) What is the competency assessment in STEM education?, and 3) How to implement competency assessment in STEM education?

Theoretical Framework

Competency in this paper refers to the knowledge, skills, and attitudes possessed by individuals. Attitudes in this context refer to self-beliefs, affective, behavioral, cognitive, and motivation.

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IJMOE
EISSN: 2637-0905
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Assessment in this paper refers to the evaluation of efforts done by the student to obtain specific learning objectives or learning outcomes. Therefore, competency assessment for STEM education in this context refers to the interdisciplinary assessment approaches that can be used to assess or evaluate the student's knowledge, skills, and attitudes. This competency is needed for their future needs and brings benefits to the country's development by providing a talented workforce.

Method

In this paper, SLR was conducted by following the PRISMA 2020 guidelines. A review across reputable databases including Scopus, Emerald, Science Direct, and Springer Link was screened based on the predefined inclusion and exclusion criteria.

Systematic Searching Techniques

Four phases of PRISMA 2020 guidelines which consist of identification, screening, eligibility, and included were used in this SLR. These phases enabled the authors to come across, organize, and synthesize the findings in SLR more transparently.

Identification

In the identification phases, the related articles are reviewed across different databases, such as Scopus, Emerald, Science Direct, and Springer Link. In this process, three methods of search were conducted. First, using the Boolean search, "+, -, AND, OR". Second, by considering the synonyms of assessment, related concepts, and variations of keywords. Three primary keywords were identified in this SLR: STEM education assessment, STEM competency assessment, and competency assessment in STEM education. Additional keywords such as STEM skills, attitudes towards STEM, belief in STEM, and other relevant keywords (Table 1). Third, reviewing the relevant articles was conducted in ResearchGate databases as backup support. After the identification process, the potential articles are 2,208.

Table 1: The String Used in the Databases Search

Database	Search String
Scopus	(TITLE-ABS-KEY (stem AND education AND assessment) AND TITLE-ABS-KEY (competency AND assessment AND in AND stem AND education) OR TITLE-ABS-KEY (stem AND competency AND assessment) OR TITLE-ABS-KEY (stem AND skills) OR TITLE-ABS-KEY (attitudes AND towards AND stem) OR TITLE-ABS-KEY (belief AND in AND stem))
Emerald	STEM competency assessment OR (STEM competency assessment) OR (Competency assessment in STEM education) OR (STEM skills) OR (attitudes towards STEM) OR (belief in STEM)
Science Direct	STEM education assessment, STEM competency assessment, Competency assessment in STEM education
Springer Link	STEM education assessment, STEM competency assessment, Competency assessment in STEM education

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Screening

The screening phase was conducted manually based on the criteria in Table 2. The screening phase focused on articles published between 2013 and 2024. This period was chosen because based on the report published by the National Research Council (NRC) in 2013, Monitoring progress toward successful K-12 STEM education: A nation advancing? This report mentioned the need to develop an effective assessment system to support learning in science and mathematics by using assessments which able to measure the core concepts and practices of science and mathematics (NRC,2013). In this screening phase, English-written articles from all fields were selected to prevent misunderstanding. To enhance the findings of the study, the assessment or evaluation to enhance students learning or interest in STEM education by inquiry-based learning, project-based learning, problem-based learning, and other learning approaches are included. In the screening phase, 2,131 articles were excluded because not meet the study's requirements. Therefore, 77 articles are remaining for the retrieval.

Table 2: Criteria for Inclusion and Exclusion in Screening

Criteria	Inclusion	Exclusion
Timeline	2013 - 2024	Before 2012
Document Type	Article	Dissertation thesis, book chapter, and book, systematic literature review (SLR), meta-analysis
Language	English	Non-English
Level	Primary education to Tertiary Education	Elementary Education
Study Focus	Competency Assessment in STEM Education	Non-Competency Assessment in STEM Education

Eligibility

In the eligibility phase, after 32 papers were excluded in the not retrieved stage, the authors checked all the 45 papers recovered manually to determine the articles that satisfied the inclusion criteria by reading the title and abstract of the paper. In this phase, 31 papers were excluded for irrelevant research, such as not focusing on the interdisciplinary STEM, not relevant to the STEM subjects, and failing to meet the competency assessment criteria in this paper. Therefore, 14 papers were chosen for the next phase.

Included

In the included phase, authors conducted the quality assessment to assess the paper's quality using the criteria in Table 3 to ensure the accuracy and validation of the reviewed papers. In this phase, 14 papers were selected based on the relevant research scope, research design, research questions, and the qualitative data provided. The review findings are presented in the PRISMA flow diagram (Figure 1).

Quality Assessment Criteria

The quality assessment criteria (adapted from McDermott et al. (2004)) were conducted based on the six elements in research (Jalak & Nasri, 2019) shown in Table 3. The grading of the article is based on the four-grading suggested by McDermott et al. (2004) as shown in Table 4.

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Table 3: Quality Assessment Criteria

No	Element	Description
1	Purpose and objective	Does the article clearly state the purpose and objective?
2	Scope	Does the article clearly outline the planning, development, implementation, and completion of the research?
3	Sample	Does the article offer an adequate sample size?
4	Methodology	Does the report adequately describe the research methods, including the framework, data collection, and analysis?
5	Data	Does the report present enough data that is clearly identified and distinguishable from the interpretation?
6	Finding	Do the research results thoroughly summarize the key outcomes and receive validation and feedback from experts or other mechanisms to improve the validity of the study?

Table 4: Article Grading

Grade	Details
A	Meet six criteria
B	Meet five criteria
C	Meet four criteria
D	Meet three criteria

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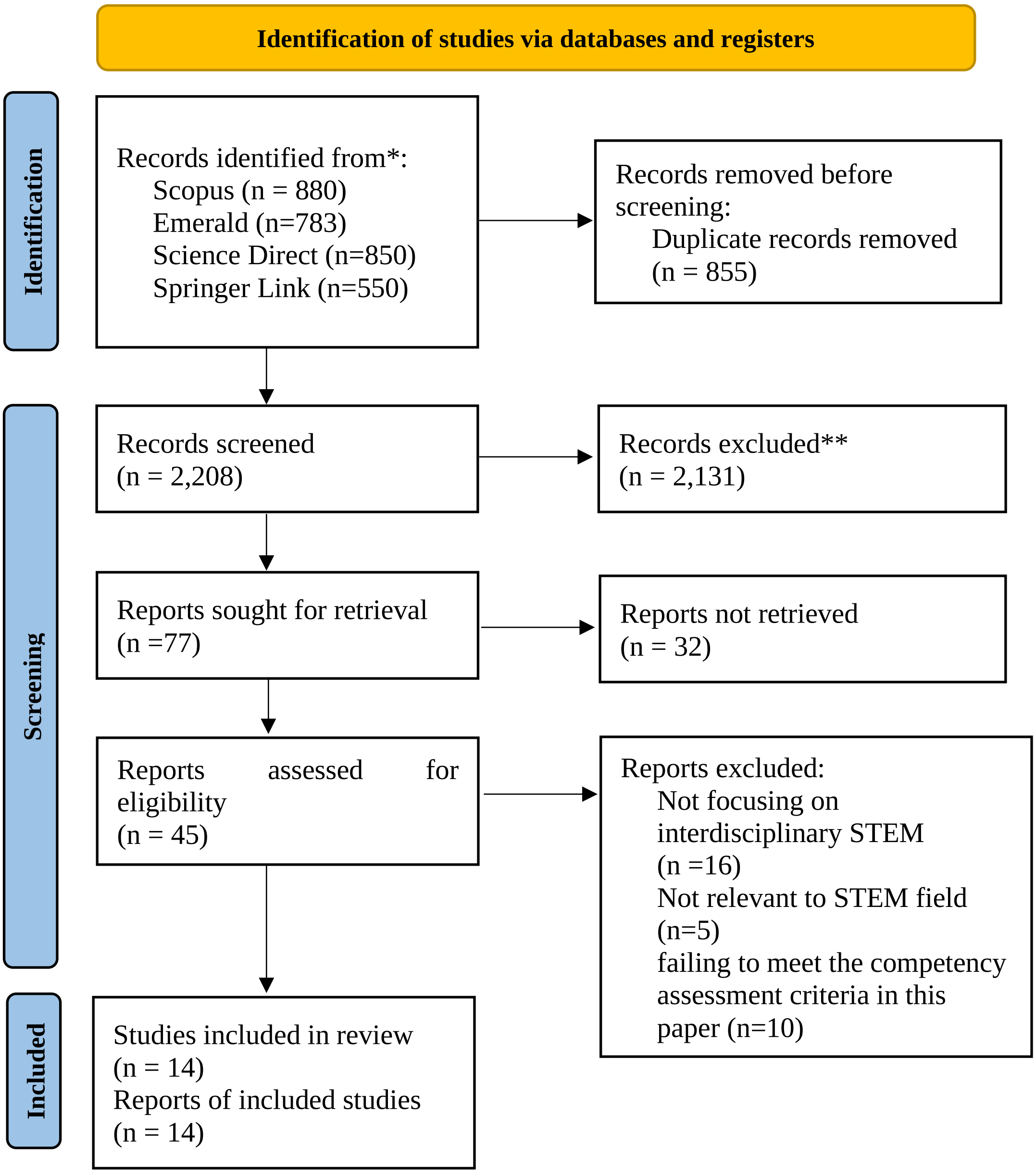

Figure 1: PRISMA 2020 flow diagram

Research Findings

To answer the questions addressed in the study, all findings were analyzed and summarized in Table 5. Table 5 shows the summary of qualifying articles based on the researcher's name, year of publication, methodology, research findings, and grade.

Table 5: Summarizes of Qualifying Articles

Researcher	Year	Methodology	Research Findings	Grade
Rommel AlAli	2024	Experimental Design, Survey Research	This study emphasizes the importance of incorporating PoPBL into STEM education to enhance essential skills like problem-	A

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			solving, creative thinking, collaboration, and effective communication.	
Maura A. E. Pilotti, Khadija El Alaoui, Hanadi M. Abdelsalam & Omar J. El-Moussa	2024	Grounded theory	This study aimed to compare the communication skills, and professional competencies of STEM students with non-STEM students. Survey results before and after the epidemic indicate that female STEM majors face challenges in readjusting to campus teaching. The findings reveal that female STEM learners continue to be underrepresented and encounter performance challenges in the post-pandemic environment.	A
Kirksey, J. J., Mansell, K. & Lansford, T.	2023	Correlational Research	The findings show that for people with visual and/or hearing impairments, there is a significant association between problem-solving skills and having a STEM degree.	A
Takashi Yamashita, Donnette Narine, Wonmai Punksungka, Jenna W. Kramer, Rita Karam & Phyllis A. Cummins	2023	Correlational Research	This study offers preliminary implications for education, workforce, and social policies aimed at advancing the nation's economy and well-being. It also guides future research in unraveling the complex interrelationships among key social indicators	A
Jessie B. Arneson & Erika G. Offerdahl	2022	Test	The findings have implications for instructors in designing and interpreting student assessments and urge researchers to explore the relationship between student cognition and multidimensional assessments more deeply.	A
Loretta Brancaccio-Taras, Judy Awong-	2022	Case Study	The findings enhanced the student experience by	A

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Taylor, Monica Linden, Kate Marley, C. Gary Reiness, & J. Akif Uzman			integrating evidence-based teaching methods and developing curricula that emphasize a deeper understanding of scientific principles, competencies, and the scientific process.	
Tiffany K. Gunning, Xavier A. Conlan, Paul K. Collins, Alecia Bellgrove, Kaja Antlej, Adam P. A. Cardilini and Catherine L. Fraser.	2022	Case Study	The findings indicate that online self-assessment and intra-team peer assessment strategies offer teaching teams evidence-based evaluations of student engagement in team activities. When these online strategies are combined with subject-specific team-based assessments, they provide teachers with a consistent approach to administering and participating in team-based evaluations within their schools.	A
Erin E. Turner, Amy Roth McDuffie, Amy Been Bennett, Julia Aguirre, Mei-Kuang Chen, Mary Q. Foote & James E. Smith	2021	Test	The findings demonstrate high reliability and low standard error for the assessment that supports the grades 3 to 5 framework and the evaluation of mathematical modeling instruction, as well as for future research in STEM learning.	A
Vianney Lara-Prieto & Gilberto E. Flores-Garza	2022	Experimental Design	The findings proved that students can rapidly acquire knowledge and apply it to create practical, innovative solutions for real-world challenges in industry. Robust partnerships between academia and industry are essential for fostering both disciplinary and transversal competencies in students by encouraging them to tackle real-life problems.	A

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Allyson Stokes, Janice Aurini, Jessica Rizk, Robert Gorbet & John McLevey	2022	Observation, Survey Research	The results indicate that robotics serves as an effective instrument for promoting the development of STEM and 21st-century skills. The updated assessment tools acknowledge robotics as one of the various means to fulfill curricular goals. Additionally, this study identified several barriers to the broader implementation of robotics in teaching and learning, such as inadequate integration of curriculum and assessment, a lack of resources, and insufficient professional development and support.	A
Graciano Dieck-Assad, Alfonso Ávila-Ortega and Omar Israel González Peña	2021	Experimental	In this competence evaluation study, students were introduced to conceptual, procedural, and attitudinal content relevant to addressing challenges posed by an industrial partner. Those collaborating with the industrial partner demonstrated greater engagement and motivation to learn the subject compared to students in traditional classroom settings.	A
Jennifer A. Czocher, Kathleen Melhuish, Sindura Subanemy Kandasamy, Elizabeth Roan	2021	Survey Research	This study illustrates that combining mathematics education with engineering education can tackle two facets of the persistence issue in engineering and STEM disciplines: the focus on modeling as a means to create more authentic learning experiences (Niss et al., 2007), and the necessity for strategies that enable academic units to collect	A

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			localized data on student progress toward project objectives.	
Li-Ting Cheng, Thomas J. Smith, Zuway-R. Hong and Huann-shyang Lin	2021	Experimental Design	The teaching methods employed in this study allowed for a range of student learning outcomes, highlighting potential ways in which specific groups of students may react to an inquiry-based pedagogy.	A
Jennifer Rhode Ward, H. David Clarke, and Jonathan L. Horton	2014	Experimental Design, Survey Research	The findings indicate that the rivised curriculum enhanced students' knowledge and awareness of plant science topics, improved their scientific writing skills, strengthened their understanding of statistics, and increased their interest in conducting research.	A

STEM Education Assessment

In education, assessment is used to identify the student's strengths and weaknesses in learning, so that the educator can provide a specialized academic support program or intervention to help the students (Yambi, 2018). According to Brown (1990), assessment consists of a series of measures aimed at evaluating an individual's characteristics, involving the collection and interpretation of information regarding a student's learning level. Issues in assessment in STEM education have been raised by many researchers, such as Akiiri, Tor & Dori (2021), Gao et al. (2020), and Bicer et al. (2017). They raised the same issue: the absence of an integrated STEM education assessment framework or model for assessing STEM education. Although Bicer et al. (2017) suggested a hypothesized STEM assessment model, they found it not possible to use this model because primary education does not have the assessment or evaluation of student’s technology and engineering. This point is supported by Gao et al. (2020). Gao et al. (2020) suggested that integrated STEM assessment should be started in secondary education. In the study conducted by Akiiri, Tor, & Dori (2021), it was found that the predominant assessment method consisted of standardized tests featuring both open-ended and closed-ended questions. The finding by Ng & Mazlini (2022) in Figure 2 shows that the assessment in STEM education gained the attention of researchers in STEM education, and the number of research articles on the assessment in STEM education increased between 2016 and 2021.

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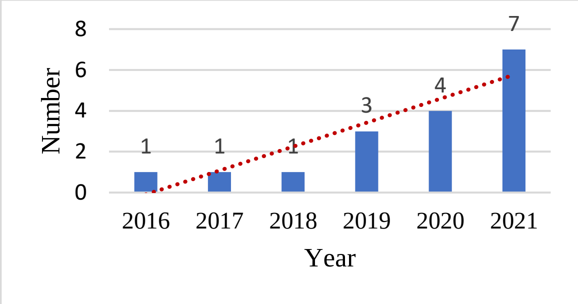

Figure 2: Trend Of The research articles About The Assessment In STEM Education
Source: Ng, C. H., & Mazlini, A. (2022). Issues in Assessment on Interdisciplinary STEM Education: A Systematic Literature Review. Manuscript submitted for publication.

Competency Assessment in STEM Education

Traditional assessment is a teacher-structured, selecting a response, a recall/ recognition, and contrived method to assess the students understanding or knowledge (Ferns & Comfort, 2014). Competency assessment is the foundation for evaluating individuals' skills, knowledge, and abilities to facilitate professional development (Axiak et al., 2024). To access the STEM competency, we need to have a clear definition of the competency in sustainability STEM education for the future workforce in country development. According to Bakarman (2011), the ASK (attitude, skill, knowledge) is the competency that needs to be assessed. Bakarman (2011) cited Vinke defines competency as an individual's ability to select and apply the knowledge, skills, and attitudes required for effective behavior in a particular professional, social, or learning context. However, through this paper, the authors noticed there was no consensus on the definition of STEM skills and the competency model or framework that can be used for competency assessment in STEM education. Therefore, the STEM competency assessment model is needed as the guidelines for assessing the student's STEM competency.

Materials and Resources

Materials and resources are one of the major issues in interdisciplinary STEM assessment. A suitable model or framework is absent for assessing students' competency in STEM education. Besides that, there were no assessments or evaluations on technology and engineering in primary education (NRC, 2013). Based on the findings, Becker & Park (2011) suggested that the engineering approach in STEM education aims to help students cultivate knowledge and skills in science and mathematics. Blackley et al. (2018) suggested the *Makerspace* approach by integrating science, technology, and engineering in primary education, but this project is more on the development of project-based and inquiry-based learning, not significant in the STEM competency assessment. Although Jones & Robert (2024) suggested an integrated STEM literacy position before technology literacy in their papers. However, their paper focuses on secondary education and above.

Teacher's Competency

Another major issue in STEM competency assessment is the teacher's competency. In most of the reviewed papers, authors find that most of the teachers are using monodisciplinary assessment to measure student's understanding of single subjects (Arneson & Offerdahl, 2022 & Dieck-Assad et al., 2021) and some of them measured the students' interest in STEM as an attitude toward STEM (AlAli, 2024 & Ward et al., 2014). According to Akiiri, Tor & Dori (2021), most teachers like the traditional or summative assessment. The teachers feel that using the standardized assessment or test with open and closed questions makes it easy to measure

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students' understanding of the subjects. Akiiri, Tor & Dori's (2021) findings show that for the formative assessments, oral tests are the least preferred method while writing the experimental reports is the most preferred method by teachers.

STEM Skills

During the reviewing papers for this SLR, the authors noticed that there was no consensus about STEM skills and the definitions of STEM skills are inconsistent (Siekmann & Korbel,2016). Ng (2019) defined STEM skills as skills required to carry out STEM-related tasks including cognitive, manipulative, technological skills, and collaboration and communication skills. Some researchers interpreted 21st-century skills as STEM skills. AlAli (2024) asserts that integrating Project-Oriented Problem-Based Learning (PoPBL) into STEM education activities will enhance students' 21st-century skills. Although the definitions for STEM skills may vary, in the context of competency-based learning and assessment, there is no doubt that skills are a must.

Time

The time constraint also limited the STEM competency assessment. The primary and secondary syllabuses have developed over the years, which means the students need to master the subject content knowledge and skills over the years. From the papers review, authors found that the assessment or evaluation focuses on the single subject content and students' interest based on the project in the year. Most researchers do not have follow-up activities or assessment instruments for the subsequent year, this is one of the reasons that may cause the assessment in STEM education difficult to implement.

STEM competency assessment is an authentic and interdisciplinary approach that should begin at the primary school level because primary school is the key to learning all knowledge and skills and establishing the right attitude towards learning and STEM education.

Conclusion

In this study, the authors found that the traditional assessment methods in STEM education are primarily monodisciplinary approaches and focus on measuring motivation or interest in STEM. These methods are typically summative or exam-based. In contrast, competency assessments emphasize the development of student's knowledge, skills, and attitudes toward STEM education. Competency assessment in STEM education has garnered increasing attention from researchers in recent years. From the trend in STEM education research, the authors found that in recent years, the research in STEM education has tended to the assessment or competency assessment for STEM education. However, most STEM education assessments are directed toward secondary and higher education. From the authors' perspective, competency assessment in STEM education should begin at the primary school level so that the STEM competency assessment can contribute to the positive development of STEM education.

Despite its importance, conducting a competency assessment with an interdisciplinary approach is one of the challenges. According to Sander (2009), STEM education cannot be implemented in isolation; it must be integrative of the ideas and practices of the four STEM subjects. To enhance the accuracy and effectiveness of the implementation of the STEM competency assessment, it is crucial to have a suitable assessment model or framework as the standard for STEM competency assessment. With a model or framework, STEM educators can

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follow the model or framework to design relevant tasks for the students systematically. Ultimately, STEM competency assessment is essential for nurturing a skilled workforce to drive national development.

Acknowledegment

This systematic literature review (SLR) benefited immensely from the guidance of my supervisor, Assoc. Prof. Dr. Mazlini Adnan. We would like to thank all the dedicated committee members of the International Postgraduate Colloquium 2024 (IPAC 2024) at Sultan Idris Education University (UPSI)

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