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Unveiling STEM Education Conceptions: Insights from Pre-Service Mathematics and Science Teachers

Pandu Jati Laksono[1,*], Suhadi[2], Arvin Efriani[3]
[1]Chemistry Education Study Program, Universitas Islam Negeri Raden Fatah Palembang, Sumatera Selatan, Indonesia
[2]Physics Education Study Program, Universitas Islam Negeri Raden Fatah Palembang, Sumatera Selatan, Indonesia
[3]Mathematics Education Study Program, Universitas Islam Negeri Raden Fatah Palembang, Sumatera Selatan, Indonesia

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ABSTRACT

Purpose of the study: This study aims to analyze STEM education conceptions among pre-service mathematics and science teachers, focusing on their perceptions, understanding, and readiness to implement STEM education. The research seeks to identify gaps in STEM comprehension to inform teacher preparation program development.

Methodology: This descriptive quantitative study describes the STEM concept among prospective science and mathematics teachers using an online questionnaire with Likert scale and open-ended questions. Data were analyzed using descriptive statistics, such as mean and standard deviation, and validated with Gregory's content validity formula, and Cronbach's alpha.

Main Findings: Main findings indicate that 14.58% of respondents demonstrated very high STEM conception with scores exceeding 112.37, while 31.25% exhibited high conception within the range of 98.83 to 112.37. Conversely, 41.67% showed low conception with scores between 85.33 and 98.82, and 12.50% had very low conception, scoring below 85.33. Overall, only 45.83% of pre service teachers possessed adequate STEM conception, highlighting that 54.17% require strengthening in their understanding of STEM. Mathematics is seen as an essential foundational element in STEM education, with technology integration being key to improving learning outcomes. This study highlights the need for curriculum revision and professional development to improve STEM readiness among preservice teachers.

Novelty/Originality of this study: This study identified a lack of STEM concepts among preservice mathematics and science teachers, and highlighted the urgency of revising the curriculum with an interdisciplinary approach that connects theory and practice. Limitations include self-reported data and a limited focus, so a larger study is needed.

Corresponding Author:
Pandu Jati Laksono,
Chemistry Education Study Program, Universitas Islam Negeri Raden Fatah Palembang,
Pangeran Ratu Street, Seberang Ulu 1, Jakabaring, Palembang, Sumatera Selatan, Indonesia
Email: pandujati_uin@radenfatah.ac.id

1. INTRODUCTION

Integrating 21st century skills into the education curriculum is increasingly recognized as essential to preparing students for the demands of Industrial Revolution 4.0 and Society 5.0. Education systems must evolve to incorporate skills such as critical thinking, creativity, collaboration, and digital literacy, which are critical in a rapidly changing technological landscape [1]. The industrial revolution 4.0 is characterized by a combination of advanced technologies, including artificial intelligence, robotics, and the Internet of Things, which requires a workforce with expertise in these fields [2], [3]. Research shows that students who engage in STEM (Science, Technology, Engineering, and Mathematics) education are better prepared to navigate the complexities of modern industry, because they develop problem-solving skills and innovative thinking [4], [5]. The urgent need to reform educational practices to emphasize 21st century skills is essential to developing a workforce that is able to thrive in an evolving socio-economic context. This is in line with the vision of STEM education which focuses on improving problem-solving skills and their integration in the community.

In the field of STEM education, significant challenges continue to exist that hinder the effective implementation of this educational paradigm. Many students find STEM education too challenging and uninteresting, which reduces their interest and participation [6], [7]. STEM education provides integrative learning experiences and innovative pedagogical approaches [8]. Research shows that blended learning environments can increase student engagement and collaboration; they aid in technology integration and adequate professional development for educators [9], [10]. Therefore, it is necessary to create a more inclusive and effective STEM education system that not only attracts students but also prepares them for the demands of the future workforce. In short, overcoming the barriers to STEM education requires a generation of learners who are not only skilled but also contribute to the fields that will shape the future. This future generation will be skilled if they have teachers who have the ability to integrate various fields of science.

Pre-service teachers' perceptions of challenges in STEM education are an important area of research, particularly in the context of the Fourth Industrial Revolution. The challenges faced by pre-service mathematics and science teachers in STEM education are highlighted by the urgent need for a skilled workforce capable of navigating the complexities of the Fourth Industrial Revolution. The barriers encountered by teachers were pedagogical challenges, curriculum challenges, structural challenges, concerns about students, concerns about assessment, and lack of teacher support [11]. Pedagogical challenges in the realm of Pedagogical Content and Technology Knowledge (TPACK) among pre-service teachers are becoming an important issue in efforts to effectively integrate technology into STEM teaching [12]. Research shows that many preservice teachers feel unprepared to leverage technology in their teaching practice, which can hinder their ability to engage students and foster important 21st-century skills such as problem-solving and collaboration [13], [14]. Research finds that pre-service teachers often lack confidence in their ability to implement technology-enhanced learning environments, which directly impacts their teaching efficacy and student engagement [10]. The learning curriculum that supports science still faces various challenges and has a number of shortcomings that need to be addressed [15]. Teacher perceptions and abilities also have a significant influence on the success of STEM. Therefore, addressing the gaps in integrated learning is critical to preparing future educators to meet the demands of modern STEM education and to cultivate a generation of competent learners.

In addition, the urgency of this research is reinforced by the need to improve the pedagogical skills of pre-service teachers in the face of rapidly evolving educational technology. Many positive views of STEM education reflect a desire to maintain this education. However, contradictions in its application are encountered during learning. Many pre-service teachers reported feeling overwhelmed by the pace of technological change and expressed concerns about their ability to adapt their teaching methods [16], [17]. Professional development that emphasizes STEM thinking and STEM career awareness is essential to realizing STEM education that supports sustainable development [18]. However, challenges such as accountability pressures and resource constraints can demotivate teachers, which ultimately negatively impacts student success in STEM education. [19]. These sentiments and shortcomings highlight the need for comprehensive training programs that not only focus on content knowledge but also emphasize the integration of technology into pedagogical practices [20]. For example, research has shown that pre-service teachers who receive targeted training in technology integration are more likely to develop positive attitudes toward the use of technology in their classrooms, which can lead to improved student learning outcomes [21], [22]. An investigation of pre-service teachers' perceptions of the challenges of STEM education to inform teacher training programs and ensure that future educators are adequately prepared to navigate the complexities of teaching in the industrial revolution 4.0.

This study aims to analyze the concept of STEM education among pre-service mathematics and science teachers, focusing on their perceptions, understandings, and readiness to implement STEM education. Identifying gaps in STEM understanding is important to inform the development of effective teacher preparation programs. Pre-service teacher perceptions of STEM education are a significant area of investigation as they contribute to the development of relevant educational strategies and teacher training programs. Previous research suggests that pre-service teachers generally have positive attitudes toward STEM education, where science, technology, engineering, and mathematics are viewed as complementary disciplines [23]. In addition, the study also revealed that pre-service elementary school teachers showed positive intentions towards STEM teaching, reflecting their readiness to adopt an integrative pedagogical approach [24], [25]. These findings underscore the growing awareness of pre-service educators about the importance of STEM education in developing critical thinking and problem-solving skills essential to the challenges of modern society. Pre-service teachers' perceptions are influenced by their educational background and experiences, and a deeper understanding of these factors is needed [26]. However, challenges in implementing integrated STEM education, such as resource constraints and accountability pressures, underscore the importance of more specific research to address these issues. [27]. Therefore, this study is expected to provide valuable insights into how to prepare pre-service educators to meet the demands of STEM teaching, while increasing the effectiveness of STEM education implementation in schools.

2. RESEARCH METHOD

This study uses a quantitative descriptive approach that aims to describe the STEM conception of pre-service science and mathematics teachers. This study is a method used to describe or analyze research results but is not used to draw broader conclusions [28]. This approach was chosen because it is appropriate to reveal and describe the respondents' understanding and perception of STEM education systematically and measurably. The research procedure was carried out in three main stages as stated by Arikunto. The research procedure was carried out in three main stages as stated by Arikunto [29]. The first stage is preparation, which includes the preparation, validation, and reliability of the instrument. At this stage, the instrument that has been prepared is validated by experts and improvements are made according to the input given. The second stage is implementation, where the questionnaire is distributed to respondents via Google Form and data collection is carried out. The third stage is data analysis, which includes data tabulation, descriptive statistical calculations, category determination, and interpretation of results.

The subjects in this study were 48 pre-service teacher students from the mathematics, biology, chemistry, and physics education study programs. The selection of subjects was respondents who were pre-service teachers in fields integrated in STEM education. In this case, the sample used was purposive sampling, namely a sampling technique with certain considerations according to the research objectives to be achieved [30]. The sample selection criteria included pre-service teachers who were in semesters 5–7, because they were considered to have basic competency in their respective fields. Pre-service teachers who were taking courses related to STEM education

The research instrument was validated using Gregory's content validity which involved an assessment from at least two experts. Content validity is the validity obtained after analyzing, tracing or testing the content contained in the evaluation instrument [31]. The instrument used was validated using the Gregory formula and obtained a content validity coefficient of 0.875. The validity criteria are included in the very high category so that they are suitable for use [32]. The reliability of the instrument was tested using Cronbach's alpha to ensure internal consistency. The test results showed a Cronbach's alpha value of 0.85 for the questionnaire having a high level of reliability.

Data collection was conducted through an online survey using Google Form consisting of two parts. The survey method is a way of collecting data from certain natural places by providing treatment in data collection such as distributing questionnaires, tests, structured interviews and so on [28]. The first part is a Likert-scale questionnaire that measures the conception of STEM in various aspects studied. Respondents were asked to provide responses on a scale of 1-4, where 1 indicates strongly disagree and 4 indicates strongly agree. The second part contains open-ended questions that provide respondents with the opportunity to express their perceptions and conceptions of STEM in more depth.

Data analysis was conducted using descriptive statistics including the calculation of mean, standard deviation, minimum score, and maximum score. Determination of the category of conception level can use the calculation of ideal mean (Mi) and ideal standard deviation (SDi) adapted from previous research [33]. The results of these calculations are then used to determine the category criteria as follows:

Table 1. Category Interval

Class intervals	Category
>M+1 Std Dev	Very High
M until (M+1 Std Dev)	High
(M-1 Std Dev)-M	Low
<M-1 STd Dev	Very Low

3. RESULTS AND DISCUSSION

3.1 Perceptions of Mathematics and Science Pre-Service Teachers

This study was conducted to analyze the conception of STEM Education in pre-service mathematics and science teachers involving 48 respondents from various study programs, including mathematics, biology, chemistry, and physics education. Data were collected through an online survey using validated instruments. The research instrument consisted of two main parts: (1) a questionnaire with a Likert scale to measure STEM conception, and (2) open-ended questions to explore respondents' perceptions of STEM Education in more depth. Data analysis was carried out using descriptive statistical techniques with category determination based on the calculation of the ideal mean (Mi) and ideal standard deviation (SDi). The results of the descriptive analysis table can be seen in table 2.

Table 2. Description of Category Conception STEM Pre-Service Teacher

Category	Class intervals	F	%
Very high	>112.37	7	14.58
High	98.83 - 112.37	15	31.25
Low	85.33 - 98.82	20	41.67
Very Low	<85.33	6	12.50

The analysis of STEM Education conceptions in pre-service mathematics and science teachers showed varying results based on the established categories. Of the total 48 respondents, 7 pre-service teachers (14.58%) had a very high STEM conception with a score of more than 112.37. This indicates that this group has a very good understanding of the concept, implementation, and integration of STEM in learning. Furthermore, 15 pre-service teachers (31.25%) were in the high category with a score range of 98.83-112.37. This group showed a good understanding of STEM Education although it still needs strengthening in several aspects. An interesting finding is that the largest proportion of respondents, namely 20 pre-service teachers (41.67%), were in the low category with a score range of 85.33-98.82. Meanwhile, 6 pre-service teachers (12.50%) had a very low STEM conception with a score of less than 85.33.

The data shows a significant gap in STEM understanding among pre-service teachers, where only 45.83% (combined very high and high categories) have adequate STEM conceptions. This indicates the need to strengthen teacher preparation programs in STEM education. The dominance of the Low Category is shown by the fact that 41.67% of respondents are in the low category, indicating systemic challenges in developing STEM competencies for pre-service teachers. This finding can be an indicator that teacher education programs need to revise the curriculum to emphasize STEM integration in learning. Understanding Polarization is shown where there is a group with very good understanding (14.58%) and a group with very low understanding (12.50%). This polarization may reflect differences in exposure and experience of students to STEM learning during their education. Development Potential can be done in the high category (31.25%) indicating good development potential. This group can be a catalyst in developing STEM learning in schools when they become teachers. The data indicates the urgency to intervene with 54.17% of pre-service teachers (combined low and very low categories) who need to strengthen their STEM understanding. This intervention is important to ensure their readiness to implement STEM learning in the future.

The results of the quantitative descriptive analysis were strengthened by interviews conducted with pre-service teachers who filled out the questionnaire. In implementing STEM-based learning in the classroom, educators emphasized the importance of integration between disciplines, the use of active learning methods, and the implementation of real-world problem-based projects [34]. They suggested setting clear learning objectives, designing practical activities that combine aspects of science, technology, engineering, and mathematics, and encouraging collaboration between students. The use of technology such as simulations and data analysis tools was also considered important to support effective STEM learning [35]. The majority of participants believed that mathematics was essential in STEM learning. The main reasons given were that mathematics is the basis for understanding and developing concepts in science, technology, and engineering. Mathematics is a fundamental tool for data analysis, modeling, and problem-solving in the STEM context, enabling precise interpretation and prediction of complex phenomena [36], [37]. Its application fosters critical thinking and supports the integration of interdisciplinary knowledge. By equipping learners with mathematical skills, it prepares them to address real-world challenges innovatively and effectively.. Several participants also emphasized that mathematical skills help develop logical and critical thinking that are essential in the STEM approach.

The learning process uses various technologies to increase student effectiveness and engagement. Online learning platforms such as Google Classroom or Moodle for class management and material distribution. The use of multimedia such as interactive videos, simulations, and learning applications is also common. Some educators even integrate advanced technologies such as Augmented Reality (AR) and Virtual Reality (VR) to provide a more immersive and in-depth learning experience [38]. The ideal STEM learning plan, according to participants, involves cross-disciplinary integration with a focus on real-world projects or problems. Suggested learning methods include project-based learning (PBL), inquiry-based learning, and collaborative approaches [39]. Evaluation includes not only written tests but also assessments of projects, presentations, and student self-reflection. Educators emphasize the importance of formative assessments throughout the learning process and the use of clear rubrics to assess conceptual understanding and skills such as problem-solving and teamwork. Almost all participants stated that STEM is highly relevant to mathematics. The main reason given was that mathematics is the foundation for understanding and applying concepts in science, technology, and engineering. Mathematics is considered a universal language in STEM that allows for data analysis, modeling of phenomena, and solving complex problems. Several participants also emphasized that mathematical skills such as logical and analytical thinking are essential in developing innovative solutions in STEM contexts.

3.2 Facing STEM Challenges for Pre-service Teachers

The concept of STEM (Science, Technology, Engineering, and Mathematics) for pre-service mathematics and science teachers has become the focus of educational research in recent years. Pre-service teachers as the vanguard of education have a strategic role in implementing effective STEM learning [40]. Research shows that a strong understanding of STEM concepts by teachers is positively correlated with the successful implementation of STEM-based learning in the classroom [41]. The findings of this study revealed a significant gap in STEM understanding among pre-service teachers, with only 45.83% having adequate STEM conceptions. These results are in line with research that found that many pre-service teachers still experience difficulties in effectively integrating STEM components into their learning [42]. This is reinforced by Ejiwale's study, which identified several challenges in STEM education, including lack of teacher preparation and limited understanding of STEM integration [43].

An important aspect in the professional development of STEM teachers is the ability to integrate technology into learning. Research Kelley & Knowles emphasizes the importance of an integrated approach in STEM education, where technology and engineering are used as a context for learning science and mathematics [44]. The findings of this study reveal that pre-service teachers recognize the crucial role of technologies like AR/VR and digital learning platforms in enhancing the implementation of STEM education. Mathematics, as a core pillar of STEM, serves as a foundational framework for integrating technological tools and fostering a comprehensive understanding of interdisciplinary STEM concepts, enabling innovative solutions to real-world problems. This awareness underscores the importance of equipping future educators with the skills to effectively utilize technology in teaching. By mastering mathematical concepts, they can better guide students in applying STEM knowledge to analyze, model, and solve complex challenges. English asserts that mathematical skills are a critical component in STEM problem solving, modeling, and logical thinking development [45]. The findings of this study confirm this view, with the majority of respondents identifying mathematics as an important foundation in STEM learning.

The gaps in understanding identified in this study (41.67% low category) indicate the need for reform in teacher preparation programs. These results are consistent with the recommendations Carlisle & Weaver who emphasize the importance of strengthening teacher education programs in STEM [46]. Darling-Hammond further proposes that teacher preparation programs need to adopt an integrated approach that includes practical experiences in STEM implementation [47]. To overcome this challenge, some researchers such as Wu and Anderson recommend project-based and real-world problem-based learning approaches in STEM education [48]. This approach has proven effective in developing conceptual understanding and practical skills of pre-service teachers. In addition, Kennedy & Odell emphasize the importance of continuing professional development to enhance teachers' capacity to implement STEM effectively [49].

The limitations of this study include the relatively small sample size, which consisted of 48 pre-service teachers, and the focus on participants from a single university. This scope may limit the generalizability of the findings to broader populations of pre-service teachers in different institutions or regions. Additionally, the study relied solely on data collected through questionnaires and interviews, without incorporating other complementary methods such as classroom observations or performance-based assessments. This limited methodological triangulation may restrict the depth and breadth of the insights into pre-service teachers' STEM competencies and instructional practices. Future research should address these limitations by expanding the sample size to include participants from multiple institutions and diverse demographic backgrounds, and by employing mixed-methods approaches to obtain more comprehensive and robust data. These improvements would enhance the reliability and applicability of findings in the context of STEM education.

4. CONCLUSION

This study reveals a comprehensive picture of STEM conceptions among pre-service mathematics and science teachers, indicating a significant gap in understanding. The main findings indicate that only 45.83% of pre-service teachers have adequate STEM understanding, while the majority (41.67%) are still in the low category. The identified polarization of understanding, with 14.58% in the very high category and 12.50% in the very low category, reflects the unevenness in the development of STEM competencies during the pre-service teacher education process. The results also reveal that pre-service teachers have a good awareness of the fundamental role of mathematics in STEM learning. They view mathematics as a universal language that enables data analysis, modeling of phenomena, and solving complex problems in the context of STEM. In terms of implementation, pre-service teachers demonstrate an understanding of the importance of technology integration, project-based learning, and collaborative approaches in effective STEM learning. The weakness of this study is the uneven distribution between pre-service mathematics, chemistry, physics, and mathematics teachers.

Important recommendations can be formulated for the development of STEM education for pre-service teachers. In terms of curriculum, revisions are needed that emphasize STEM integration and the development of specific courses on STEM learning methodologies. Professional development needs to be strengthened through ongoing training programs and the formation of communities of practice, supported by collaboration with partner schools. Technology integration is a crucial aspect that requires strengthening infrastructure and developing capabilities in the use of modern learning technologies such as AR/VR. The implementation of these recommendations is expected to contribute significantly to improving the quality of STEM education in the future.

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