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Structural relationship model of conception, understanding, and self-efficacy about STEM education among pre-service science teachers

Arif Widiyatmoko[1]*, Rizki Nor Amelia[2], Tiara Dwi Wulandari[3], Melissa Salma Darmawan[4], Siti Nursulistari[5], Enjelina Desandra Putri[6]
[1,2,3]Science Education Study Program, Universitas Negeri Semarang, Semarang, Indonesia
[4,5,6]Master of Science Education Study Program, Universitas Negeri Semarang, Semarang, Indonesia
**Correspondence: arif.widiyatmoko@mail.unnes.ac.id*

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Abstract

STEM education has become a trend in the 21st century in many countries, including Indonesia. The term STEM combines four different disciplines namely Science, Technology, Engineering, and Mathematics. STEM education is a concern because it is relevant to be implemented and forms 21st century skills. This makes pre-service teacher need to understand STEM education in order to apply it to learning correctly. There are three aspects that influence the conception, understanding, and self-efficacy of pre-service science teachers. Therefore, research was conducted with the aim of analyzing the relationship between conception, understanding, and self-efficacy of pre-service science teachers towards STEM education. This study uses Quantitative Descriptive Research Design because it aims to describe and illustrate the relationship model between conception and understanding of self-efficacy in STEM education from the pre-service of Science Education study program students, Semarang State University. Based on the research that has been conducted, a structural relationship model between conception and understanding of STEM education self-efficacy among pre-service science teachers is obtained. In the model, simultaneously the conception variable and the understanding variable affect the STEM education self-efficacy of pre-service science teachers, where a higher contribution is given by the conception variable. In conclusion, conception and understanding affect the self-efficacy of science teacher candidates in STEM education.

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Introduction

21st century education aims to provide students with knowledge and skills through learning by integrating technology to face the challenges of modern life. This condition makes teachers as educators need to be able to design learning that can support the achievement of educational goals, one of which is STEM education. This is in accordance with the opinion of Teknowijoyo (2020) that education is currently leading to STEM education. STEM education is an approach and teaching that integrates Science, Technology, Engineering, and Mathematic (STEM) elements or it can also be between other disciplines and one of the STEM elements (Hata & Mahmud, 2020). Each of these STEM components plays an important role in learning including science (Kumalasari & Hasanah, 2023; Gunada *et al*., 2023). The implementation of STEM education will have a positive impact on improving the quality of science learning because the integration of each STEM component (science, technology, engineering, and mathematics) is able to improve various skills and abilities of students needed in the 21st century (Ridwan *et al*., 2022; Baran *et al*., 2021). Based on research from Nurmala *et al* (2021) and Ristiani *et al* (2021) stated that STEM-based science learning can improve creative thinking skills. Other skills that are improved are problem solving (Latifah & Hanik, 2023; Hadi 2022); critical thinking skills (Dywan & Airlanda, 2020; Putri *et al*., 2020; and Pramuji *et al*., 2020), computational thinking skills (Kristiandari *et al*., 2023); and communication skills (Hestari *et al*., 2023). In addition, STEM education also improves students' literacy skills (Hestari *et al* 2023).

STEM education can be implemented by integrating science learning models, such as Project-based Learning (PjBL), Problem-based Learning (PBL), and inquiry learning (Baran *et al*., 2021). In the Project Based Learning model, for example, by making projects as innovative products in linear learning with technical aspects contained in STEM. Project-based learning with a STEM approach is able to overcome contextual problems through learning stages in the form of design, implementation (processing), and evaluation (Diana & Sukma, 2021). The STEM approach can be applied in another learning model, namely problem-based learning. Problem-based learning with the STEM approach is able to encourage students to actively use aspects of science and engineering, gain a deep understanding of math and science, and improve problem-solving skills (Parno *et al*., 2020). PBL is related to analyzing problems by students and making solutions to these problems (Febrianto, *et al*., 2021). Meanwhile, inquiry is related to investigation or research in science learning (Chen & Chen, 2021; Widiyatmoko & Darmawan, 2023).

STEM education has become a global trend in science learning today (Nurhasnah *et al*., 2022). The Science component in STEM is related to knowledge or understanding of certain materials in science learning. The Technology component is related to the use of the internet in finding learning resources or literature. The Engineering component is related to the technique of designing a solution to science problems. While the Mathematic Component is related to mathematical calculations regarding the costs required or other science formulas (Widiyatmoko & Darmawan, 2023). Pre-service science teachers as future student educators are expected to implement STEM education in science learning in the classroom. This STEM education will also support the current curriculum, namely the Merdeka Curriculum. Therefore, it is important for pre-service science teachers to have good concept mastery, understanding, and self-efficacy towards STEM education in science learning. This makes it important to investigate the mastery of concepts, understanding, and self-efficacy of pre-service science teachers towards STEM education.

Science teacher self-efficacy has a very important role in STEM education. Self-efficacy refers to an individual's belief in their ability to succeed in specific tasks. In the context of science teachers, this self-efficacy influences the extent to which they feel capable of teaching and inspiring students in STEM fields. Science teachers' understanding and conceptualization of STEM education is crucial as it directly affects the way they deliver materials, design relevant lessons and guide students in developing the skills needed to succeed in STEM fields.

Without a strong understanding, STEM learning will not be optimized, and students may miss out on the opportunity to explore their potential in this much-needed field in the modern world. It is important to investigate the mastery of concepts, understanding, and self-efficacy of prospective science teachers towards STEM education influences the ability to innovate the development of STEM education so that science learning is more meaningful and quality. Therefore, this study aims to investigate how the mastery of concepts, understanding, and self-efficacy of pre-service science teachers towards STEM education. STEM education is very important to be implemented in science learning today because it can improve various skills and abilities of pre-service science teachers themselves and also students, and is in line with the 21st century today. This research is expected to provide data related to concept mastery, understanding, and self-efficacy of pre-service science teachers towards STEM education, which can then be followed up for evaluation, appreciation, and training on STEM.

Previous research conducted by Chen et al (2021) analyzed prospective teachers' STEM pedagogical beliefs to determine the relationship between self-efficacy and the level of need for STEM. Fenton & Essler-Pretty (2019) identified the relationship between pre-service elementary school teachers' perceptions of their effectiveness in teaching STEM. Er & Başeğmez (2020) about the relation between STEM awareness and self-efficacy belief related to STEM practice of pre-service teachers. Menon et al (2023) also examined the relationship of pre-service elementary school teachers' conceptions and self-efficacy for STEM integration in learning. However, there is no previous research that investigated concept mastery, understanding, and self-efficacy of pre-service science teachers in STEM education. In fact, the three are interrelated. A pre-service science teacher who has a good mastery of concepts and understanding of STEM education will certainly increase his confidence in teaching STEM-based science learning, so that the self-efficacy of pre-service science teachers is also good or increased. So, this will make a novelty and become one of the data references that can be used to further appreciate, evaluate, or provide training to pre-service science teachers. Based on this background, a study was conducted to analyze the relationship between conception, understanding, and self-efficacy of pre-service science teachers towards STEM education.

Method

This study used a Quantitative Descriptive Research Design because it aims to describe and illustrate the relationship model between conception and understanding of self-efficacy in STEM education from the pre-service teachers. The research subjects involved were 131 6th semester students (M_{age} = 20.312 and SD_{age} = 0.753) at the Science Education Study Program, Faculty of Mathematics and Natural Sciences, Semarang State University who took STEM courses. The participants were asked to complete the STEM conception scale (Radloff & Guzey, 2016), STEM understanding scale (Faikhamta, 2020), and STEM self-efficacy scale (Shahat *et al*., 2022) as Table 1.

Table 1. Assessment Instruments

Variable	Indicator
Conception	Typical STEM characteristics
	Relevance of S-T-E-M to its parent disciplines
	S-T-E-M linkages in STEM
	Visualization of S-T-E-M Linkages in STEM
Understanding	Nature of Science
	Nature of Technology
	Nature of Engineering
	Nature of Mathematics
	Integrated STEM
Self-Efficacy	Engineering Design Process
	Identify the Problem
	Finding Solutions
	Planning
	Production and Testing
	Communicate

The responses from the participants were then analyzed with Structural Equation Modeling (SEM) so that the relationship model between variables could be clearly visualized. There are two types of SEM analysis techniques that are most widely applied in current research, namely Covariance Based Structural Equation Modeling (CB-SEM) and Partial Least Squares-Structural Equation Modeling (PLS-SEM) (Mohd Dzin & Lay, 2021); where the two analysis techniques have differences in various aspects, especially objectives, statistical methods, and analysis requirements; but complement each other (Hair *et al.*, 2017). Technically, the researcher chose to use the PLS-SEM analysis method because there is no stable theory or results that confirm the structural relationship model between conception and understanding of self-efficacy about STEM Education. There are two sub-models that need to be confirmed first in PLS-SEM analysis, namely the outer model (measurement model; specifies the relationships between the latent variables and their observed indicators) and the inner model (structural model; shows the relationship between independent and dependent variables) (Wong, 2019).

In the outer model, there are four stages of examination, namely Cronbach's Alpha Reliability (see equation 1), Composite Reliability (see equation 2), Convergent Validity (see equation 3) and Discriminant Validity. Cronbach's Alpha Reliability (α) and Composite Reliability ρ_c are categories of Internal Consistency Reliability used to determine whether the items that make up the instrument can measure the construct consistently (Hair *et al.*, 2021). Cronbach's alpha is another measure of internal consistency reliability that assumes the same threshold but produces lower values than composite reliability (Hair *et al.*, 2021). This statistic indicates that K represents the number of construct indicators and r is the average non-redundant indicator correlation coefficient (Sarstedt et al., 2021).

$$Cronbach's\ \alpha = \frac{K.\bar{r}}{[1+(K-1).\bar{r}]} \text{ .... (1)}$$

Meanwhile, composite reliability does not assume Tau equality (Chin, 1998; Barclay et al., 1995) so that composite reliability does not assume each item/observed variable contributes equally to the construct as in Cronbach's alpha and low composite reliability values certainly reflect poor construct definition and/or multidimensional constructs (Hulland, 1999). The construct reliability statistic contains l_k which indicates the standardized outer loading of the indicator variable k of a specific construct measured with K indicators, e_k is the measurement error of indicator variable k, and var(e_k) denotes the variance of the measurement error, which is defined as $1 - l_k^2$ (Sarstedt *et al.*, 2021). Although slightly different, the interpretation of composite reliability is similar to Cronbach's Alpha with a value of 0.70 as a benchmark (Barclay *et al*., 1995).

$$\rho_c = \frac{\left(\sum_{k=1}^{K} l_k\right)^2}{\left(\sum_{k=1}^{K} l_k\right)^2 + \sum_{k=1}^{K} var(e_k)} \text{............................ (2)}$$

Similar to construct reliability, construct validity is also proven through convergent validity and discriminant validity. Convergent validity is the extent to which the construct converges to explain the variance of its indicators (Hair, 2021). Convergent validity is established when a latent construct accounts for no less than half the variance in its associated indicators (Fornell & Larcker, 1981) using Average Variance Extracted (AVE) to represent the average amount of variance explained by a construct in its indicators relative to the overall variance of its indicators, as equation (3) (Cheung *et al*., 2024).

$$\text{AVE} = \frac{\sum_{i=1}^{p} \lambda_i^2}{\sum_{i=1}^{p} \lambda_i^2 + \sum_{i=1}^{p} \text{Var}(\varepsilon_i)} = \frac{1}{p}\left(\sum_{i=1}^{p} \lambda_i^2\right) \text{........ (3)}$$

Finally, for discriminant validity, the data needs to verify that all constructs in a model are shown to be different from each other (Kock, 2020). Lack of discriminant validity in a model leads to questionable conclusions, which debate whether the true measurement results are supported by the data or obtained due to using two constructs in one model (Rasoolimanesh, 2022). One approach to prove discriminant validity using SEM-PLS is cross-loading (Al-Zwainy & Al-Marsomi, 2023) or better known as "item-level discriminant validity." (Henseler *et al*., 2015). In this approach, the loading factor on an item on its related construct must be greater than the loading factor on other constructs (Chin, 1998).

After ensuring that the outer model results are satisfactory, further analysis is carried out on the inner model by examining the Coefficient of Determination (R^2), Effect Size (F^2), and Goodness of Fit (GoF) (Al-Marsomi & Al-Zwainy, 2023). R^2 is used to assess how closely the regression predictions match the data, so this coefficient generally represents the level of variance in the dependent variable and can describe one or more predictor factors (Tenenhaus et al., 2005). Chin (1998) suggests an R^2 value above 0.67 is considered significant, but Falk & Miller (1992) recommend an R^2 value of at least 0.10 as the lowest value that the model can accept as a limit value. Effect size is a measure of the relative influence of exogenous latent variables on endogenous latent constructs with average variation in R^2 (Al-Marsomi & Al-Zwainy, 2023). The effect size of an endogenous latent variable is considered to have no effect if F^2 is less than 0.02; a small effect if F^2 is 0.02 to 0.15; a moderate effect if 0.16 to 0.35; and more than 0.35 is a significant effect (Cohen, 2013). Finally, GoF analysis aims to show how much the level of feasibility and accuracy of an overall model serves as validation in PLS-SEM with categorization of 0.10 as small GoF, 0.25 as medium GoF, and 0.36 as large GoF (Cohen, 2013). The GoF formula is the square root of the multiplication of the Coefficient of Discrimination (R^2) against the Average AVE (AVA) presented in equation (4) (Hooper *et al*., 2018):

$$\text{GoF} = \sqrt{R^2 \text{ x AVA}} \quad \text{......................................} \quad (4)$$

Results and Discussion

As previously described, the analysis begins with checking the outer model which contains information on Cronbach's Alpha Reliability, Composite Reliability, Convergent Validity and Discriminant Validity. The analysis results (see Table 2) show that the α reliability value obtained for each construct is in the range of 0.827 to 0.955; while the ρ_c value is in the range of 0.885 to 0.964. This shows that α and ρ_c are satisfactory and acceptable, so it can be concluded that the constructs of the three variables are proven to be reliable.

Table 2. Reliability and Convergent Validity

	Cronbach's Alpha	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
Conception	0.827	0.885	0.659
Understanding	0.955	0.964	0.816
Self-Efficacy	0.870	0.907	0.663

The analysis results for convergent validity and discriminant validity also concluded good validity. For convergent variables, all variables have AVE values (see Table 2) that have met the 0.5 cut off (moving between 0.663 to 0.816); while the bolded cross loading values (see Table 3; or in Figure 2 and Figure 3 shown by the numbers between the blue circle and yellow box) show the highest value on each manifest variable compared to the values on other constructs (with a loading factor distribution of 0. 790 to 0.845 for the conception construct, 0.718 to 0.885 for the understanding construct, and 0.857 to 0.918 for the self-efficacy construct), which concludes that discriminant validity has been achieved.

Table 3. Discriminant Validity: Cross Loading

	Conception	Understanding	Self-Efficacy
C1	**0.845**	0.566	0.694
C2	**0.807**	0.665	0.672
C3	**0.790**	0.579	0.650
C4	**0.804**	0.579	0.634
U1	0.528	**0.846**	0.613
U2	0.623	**0.879**	0.613
U3	0.686	**0.885**	0.696
U4	0.535	**0.726**	0.598
U5	0.605	**0.718**	0.619
SE1	0.750	0.689	**0.908**
SE2	0.766	0.738	**0.913**
SE3	0.742	0.671	**0.918**
SE4	0.744	0.670	**0.911**
SE5	0.744	0.758	**0.857**
SE6	0.675	0.662	**0.912**

Meanwhile, the results of the inner model analysis provide an R^2 value of 0.733 (above the cut off of 0.67), meaning that simultaneously the conception variable and the understanding variable have a significant effect on the self-efficacy variable by 73.3% and the remaining 26.7% is influenced by other variables not examined in this study. For the size of the influence of each exogenous latent variable on endogenous variables (presented in the form of effect size, F^2) provides a value of 0.500 for the conception variable and 0.246 for the understanding variable. Although both are included in the large effect category, numerically, the contribution of the understanding variable is smaller than the contribution of the conception variable to the self-efficacy variable. Finally, related to the level of feasibility and accuracy of a model as a whole (reflected in the GoF value), the GoF value is 0.723, which indicates that the model of the relationship between conception and understanding to self-efficacy is feasible and appropriate (further visualized in Figure 1 and Figure 2).

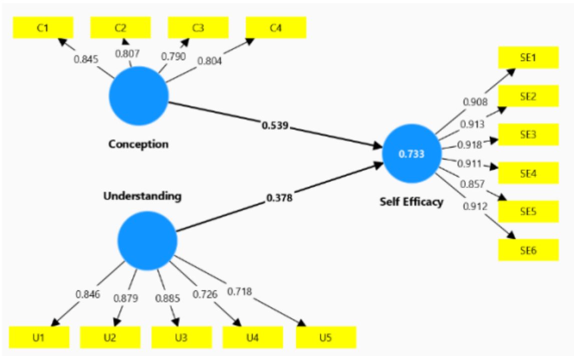

Figure 1. Structural Relationship Model of Conception and Understanding to STEM Education Self-Efficacy (Path Coefficient)

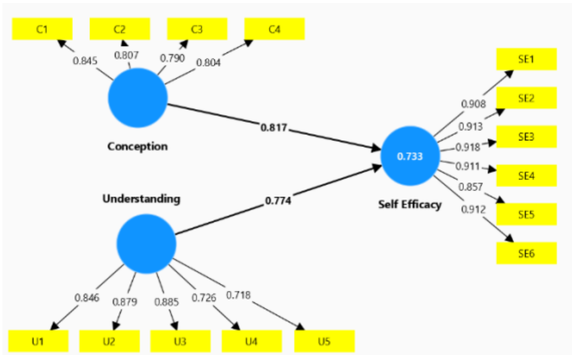

Figure 2. Structural Relationship Model of Conception and Understanding to STEM Education Self-Efficacy (Correlation Coefficient)

Figure 1 and Figure 2 show the path value and correlation coefficient of the structural relationship model built, respectively. With reference to Figure 1, the mathematical equations formed are as equation (5): $Y = 0.539 X_1 + 0.378 X_2$. The interpretation of the path coefficient value for the conception variable (X_1) of 0.539 (positive) is that if the conception variable increases by 1%, the self-efficacy variable will also increase by 0.539, assuming the value of the understanding variable remains constant. Likewise, vice versa for the variable understanding (X_2) with a path coefficient value of 0.378 (positive), if the variable increases by 0.378, the self-efficacy variable will also increase by 0.378, assuming the value of the conception variable remains constant. In addition to having a higher path coefficient value, it appears that the conception variable also has a closer relationship (0.817) with the self-efficacy variable, compared to the understanding variable (0.774) (see Figure 2).

The high value of the path coefficient, correlation coefficient, and effect size on the conception variable compared to the understanding variable shows that the conception variable contributes more to the measurement of the self-efficacy variable. Self-efficacy itself is defined by Bandura (1993) as a person's belief in their ability to succeed in a particular task in a particular situation. As such, the construct relates to perceived beliefs about one's abilities, not their actual abilities (Boeve-De Pauw *et al*., 2024). When specifically discussing science teacher candidates' self-efficacy, the concept relates to their beliefs in their ability to motivate and stimulate learning, where when teacher self-efficacy is low, teachers are more likely to rely on textbooks and prescribed curricula, which can prevent students' critical thinking, creativity, and conceptual understanding (Guo *et al*., 2012; Ramey-Gassert *et al*., 1996). Teachers' self-efficacy also has an impact on how to deal with failure and the level of patience when experiencing difficulties (Boeve-De Pauw *et al*., 2024) so that self-efficacy will play an important role in determining teaching practices, including choosing appropriate teaching activities, organizing lessons, and preparing to handle challenging situations (Bandura, 1997). In conclusion, teachers with high self-efficacy tend to use inquiry-based teaching methods and create a learner-centered environment (Watters & Ginns, 2000).

Many factors can influence STEM education self-efficacy for pre-service science teachers, where in this study the role of STEM conceptions was shown to be higher than the role of STEM understanding. In general, STEM conceptions may vary in the literature (Breiner *et al*., 2012; Brown *et al*., 2011; Bybee, 2013; English, 2016; Herschbach, 2011; Johnson, 2012), for example Bybee (2013) who suggested that although readers may be looking for a concise concept of STEM education, the most accurate concept may come from one's personal context and needs; or depend on stakeholders during STEM implementation (Hasanah, 2020). Arguably, the most robust and detailed concept of STEM education is provided by Moore et al (2015) (whose definition was adopted for this study) which is an educator's effort to engage students in engineering design and engineering thinking as a means to develop and/or explore technology with in-depth learning and application of mathematics and/or science as well as consideration of other disciplines (e.g., social studies, English/language arts). Below (Figure 3) is some documentation of the conceptions of STEM education by a sample of pre-service science teachers.

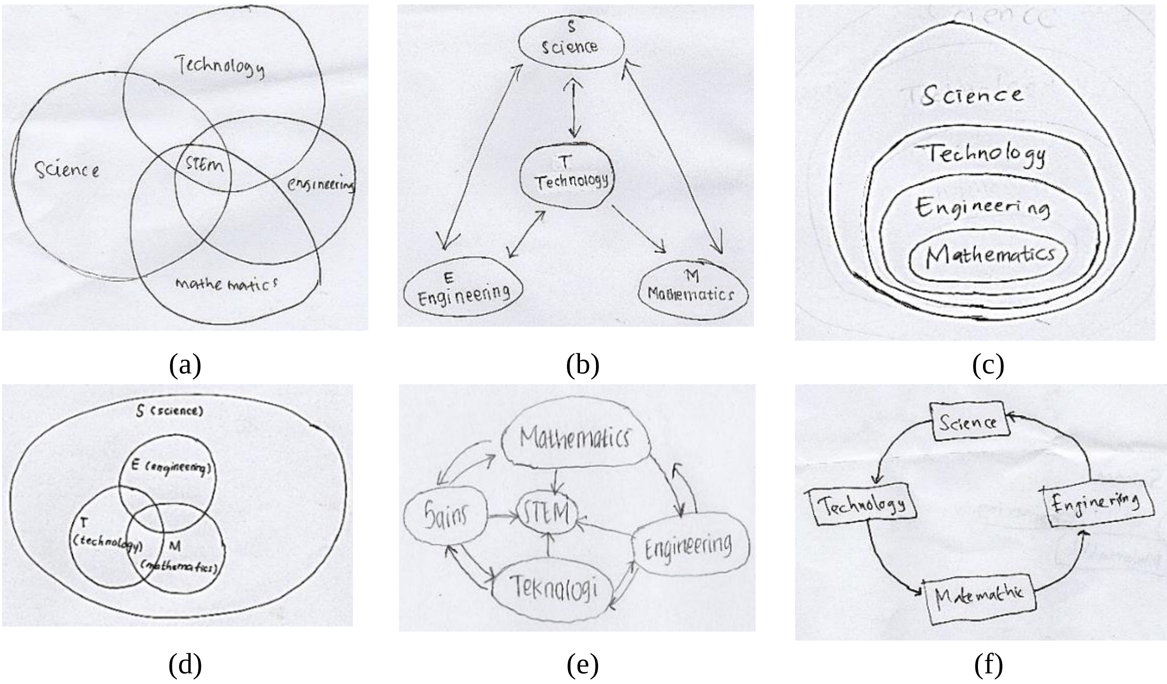

Figure 3. STEM Conceptions by a Sample of Science Teacher Candidates

Figure 3 shows that although there are differences in the conception of STEM (represented by the visualization of the connectedness of the Science, Technology, Engineering, and Mathematics components in STEM) understood by pre-service science teachers, it can generally be agreed that the S-T-E-M components in STEM have an interrelated relationship with each other. In conclusion, science teacher candidates already have a holistic STEM conceptualization, where science teachers will embed, link, and highlight elements of Science, Technology, Engineering, and Mathematics in learning topics. This finding is in line with the results of Ring *et al.* (2017) who found that the conception of STEM in science teachers after being given a three-week Intensive Professional Development Experience training that focuses on bringing integrated STEM education to science classrooms can change. In the beginning before the training, science teachers had STEM conceptions that prioritized science in their model, which certainly shows that integrating different disciplines can be difficult for teachers especially those with limited mastery of content areas (Ejiwale, 2013; Sanders, 2009). However, by the end of the training, there was a shift from science as context to integrated STEM disciplines, indicating that science teachers were willing to expand and focus their disciplines into other disciplines within STEM. This STEM conceptual change may occur because science teachers successfully develop more comprehensive conceptual constructions (Vygotsky, 1978) by reflecting on their own STEM conceptions, sharing them with others, and considering them in curriculum discussions and writing (Ring *et al*., 2017).

Regarding the lower contribution of the understanding variable to the measurement of pre-service science teachers' self-efficacy in STEM Education, it seems to be in line with the research findings of Jamaluddin *et al* (2023) which concluded that most science teachers only understand the elements of science and mathematics and do not understand the elements of engineering and technology in home science. The results of Jamaluddin *et al* (2023) also show that science teachers can only integrate STEM into a few selected topics. For example, elements of Mathematics in the topic of food and nutrition, such as calculating the amount of ingredients, calculating the Nutritional Adequacy Rate (RDA), and calculating food portions. The science teachers could also identify the creation of scientific elements in the topic of fabrics and textiles, for example in terms of the use of chemicals in fabric making and dyes in the fabric making process. However, science teachers could not mention the elements of Engineering and Technology in Home Science. The in-depth interviews further reinforced that the science teachers were still not confident to integrate the elements of Engineering and Technology in Home Science because they themselves lacked understanding of these elements. Efforts to improve pre-service teachers' understanding of STEM elements involve a variety of approaches, ranging from basic training and use of technology, to providing hands-on experience in STEM-based projects. Through this approach, pre-service teachers can build a strong foundation for teaching STEM concepts to students and prepare them for the challenges of education and careers in STEM. In conclusion, all science teachers agreed that STEM integration needs to be done in science to fit the needs of the 21st century. Finally, pre-service science teachers are not only required to master science content knowledge (Putra & Kumano, 2018; Kelley & Knowles, 2016), but also need to have high self-efficacy which is manifested in the integrity of conception and understanding in STEM education because STEM education is an integration between subjects (Stohlmann *et al*., 2012; Baran *et al*., 2021).

Conclusion

Based on the research that has been conducted, a structural relationship model between conception and understanding of STEM education self-efficacy among pre-service science teachers is obtained which is valid (fulfilling discriminant validity and convergent validity), reliable (in terms of Cronbach alpha and composite reliability), feasible, and appropriate. In the model, simultaneously the conception variable and the understanding variable affect the STEM education self-efficacy of pre-service science teachers, where the higher contribution is given by the conception variable. Suggestions for future research are to analyze efforts to improve pre-service science teachers' conception and understanding of STEM in order to have a positive impact on STEM education self-efficacy and improve the quality of education in the 21st century.

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Credit Authorship Contribution Statement

Arif, Rizki, Tiara: Conceptualization, Methodology, Analysis, Writing – original draft, Writing – review & editing. **Melissa, Siti, Enjelina**: Results, Discussion, Resources, Writing – original draft, Writing – review & editing.

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