DEVELOPING INDICATORS FOR SCIENCE TEACHER COMPETENCY IN STEM-ESD LEARNING

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ABSTRACT

Science, Technology, Engineering, and Mathematics (STEM) education focused on Education for Sustainability Development (ESD) can help students improve STEM skills and science procedures. STEM-ESD teachers are needed to acquire these competencies. This study aims to develop and determine the validity and reliability of STEM-ESD competency indicators for science teachers with Technological Pedagogical Content Knowledge (TPACK) standards. Descriptive research includes competency indicator development, indicator testing, and validation. This study employed Rasch modelling to assess 51 questionnaire items. This study included 108 science teachers. The results showed that STEM-ESD competencies were developed into 3 domains: planning, implementing, and professional development. The planning domain includes Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and TPACK. Meanwhile, the implementation and professional development domain includes TPACK indicators. The results of testing with the Rasch model show that the competencies developed can measure what should be measured (with no other dimensions outside the construct) because the raw variance explained by measures is 69.7%, which is classified as a very good criterion. Then, the unexplained variance in the 1st-5th period shows results that are smaller than 15%. A total of 42 indicators were declared valid. Furthermore, the reliability results are shown by the Cronbach alpha result of 0.99 with a very good category. The development and validation of this indicator is expected to be a reference for teachers to know what competencies they must have in teaching STEM-ESD in science learning.

Keywords: *science teacher competency, TPACK, STEM, ESD, STEM-ESD learning*

1. INTRODUCTION

Teacher competency development is part of the key steps to encourage the development of students' core competencies and produce outstanding students who are able to adapt to global developments in the future (Byrd & Alexander, 2020; Cebrián et al., 2020). Thus, teacher competence has a positive influence on the formation of students' core competencies. In the field of science education, students have strived to achieve student literacy competencies, inquiry, and engineering using sustainable technology (Bellová et al., 2023; Lind et al., 2022). In the practice of science learning, competent science teachers are the main factor that determines student success in science learning and competency development. The main challenges for science teachers in teaching science in schools include understanding the discipline and its subject matter, understanding students, understanding teaching practices, understanding the learning environment, and subject specialization (Ye et al., 2021). To answer and overcome these challenges, it is necessary to develop science teacher competencies.

STEM-ESD learning seeks to integrate science learning by training students to do engineering using technology for sustainability in order to solve everyday problems. Science learning that integrates STEM-ESD has not been widely implemented in schools. Most teachers are not familiar with STEM-ESD learning, so they cannot optimally facilitate it in the classroom. Not many teachers have a background in STEM learning for sustainability, which is one of the factors that has not been widely implemented in the classroom (Hamad et al., 2022; Velázquez & Rivas, 2020). In order to develop these competencies, most can be obtained through training, workshops, seminars or other activities.

TPACK is one of the professional knowledges that teachers must develop. Teachers' professional knowledge is a determining factor in the development of students' knowledge. Teachers are expected to carry out an effective learning process by using their professional knowledge (Chai et al., 2020; Tondeur et al., 2020). Therefore, teachers must develop TPACK maximally in STEM-ESD integrated science learning. TPACK-based STEM-ESD competency development is an important step that must be prepared and given to teachers to prepare their competence in the application of STEM-ESD in science subjects. In order to develop these competencies, the first step that needs to be done is to develop TPACK-based STEM-ESD competency indicators.

TPACK is seen as a highly qualified knowledge that teachers must possess. In STEM-ESD learning, teachers must have knowledge that includes the relationship between content, pedagogy and technology, which is TPACK (Chai et al., 2020; Irmita & Atun, 2018). TPACK describes the integrated relationship between knowledge of the subject matter to be learned and taught (content knowledge/CK), knowledge of teaching and learning processes and practices or strategies (pedagogical knowledge/PK), and knowledge of technological tools and the skills needed to operate a particular technology (technological knowledge/TK). In addition, the TPACK framework also combines these three types of knowledge into four other types of knowledge, namely knowledge about teaching practices that are appropriate to the subject content (pedagogical content knowledge/PCK), knowledge about technological tools and skills that are appropriate to learning practices and strategies (technological pedagogical knowledge/TPK), knowledge about the relationship between subject matter and the use of technology (technological content knowledge/TCK), and knowledge that has a relationship between knowledge about material content, pedagogy, and technology to create better learning (technological pedagogical content knowledge/TPACK).

Based on this, TPACK can be used as a new knowledge framework that can be useful for preparing and developing teacher competence in teaching STEM-ESD. This study aims to develop and determine the validity and reliability of indicators of STEM-ESD competence of science teachers using TPACK standards. In this study, science teachers' competence in teaching STEM-ESD will be developed, and this will be divided into the domains of planning, implementation, and professional development. Later, the domain will be classified into TPACK-based competency standards and developed into each indicator. These competencies are expected to be a reference for teachers to have awareness, desire, and action in developing their competencies, especially in science learning integrated with STEM for sustainability.

2. METHODS

2.1 Research design

This study used descriptive research. Indicators were developed through the following procedures: competency indicator development, indicators testing, and validation. Based on the pilot test, the collection of items was then validated to ensure that the indicators met the reliability and validity criteria. The development of domains, standards, and indicators of science teacher competencies in STEM-ESD learning is designed based on underlying theories, previous research results, and literature that is in accordance with these competency components. This resulted in a new competency framework.

The domain in the STEM-ESD competency indicator is divided into 3 domains, namely planning, implementing, and professional development. The domain becomes a reference in determining the standards and indicators of science teacher competence. The standards and indicators of science teacher competence in STEM-ESD learning consist of 7 standards, 9 indicators for the planning domain, 1 standard and indicator for the implementing domain, and 1 standard, which includes 2 indicators for the professional development domain. Subsequently, it was developed in the form of a questionnaire using a 1-4 Likert scale with scale descriptions ranging from 'very unsuitable' to 'very suitable'. The number of questionnaire items was 51 items, with 36 items in the planning domain, 7 items in the implementing domain, and 8 items in the professional development domain. Details of the development of domains, standards, and indicators of science teacher competencies in STEM-ESD learning can be seen in Table 1.

Table 1: Mapping of STEM-ESD Domains, Standards, and Competency Indicators

Domain	Standard	Indicator	Number of Statements
Planning	STEM-ESD Content knowledge (CK)	Teacher knowledge of content in STEM-ESD learning	5
	STEM-ESD Pedagogical knowledge (PK)	Teachers' knowledge of STEM-ESD learning management	3
	STEM-ESD Technology knowledge (TK)	Teachers' knowledge of technology that supports STEM-ESD learning	2
	STEM-ESD Pedagogical content knowledge (PCK)	Teacher knowledge in developing STEM-ESD lesson plans	8
		Teachers' skills in developing STEM-ESD lesson plans	5
	STEM-ESD Technological pedagogical knowledge (TPK)	Teachers' knowledge in utilizing technology in accordance with STEM-ESD learning strategies	3
	STEM-ESD Technological content knowledge (TCK)	Teachers' knowledge in utilizing technology related to STEM-ESD learning content	3
	STEM-ESD Technological Pedagogical Content Knowledge (TPACK)	Teachers' knowledge in integrating content, pedagogical and technological components in STEM-ESD learning	4
		Teachers' skills in designing STEM-ESD learning that integrates content, pedagogical, and technological components in STEM-ESD learning	3
Implementing	STEM-ESD Technological Pedagogical Content Knowledge (TPACK)	Teachers' skills in integrating content, pedagogical and technological components in STEM-ESD learning implementation	7
Professional Development	STEM-ESD Technological Pedagogical Content Knowledge (TPACK)	Engagement in professional development related to STEM-ESD learning	4
		Collaboration in STEM-ESD learning	4

The development of indicators, as shown in Table 1, is known to have been done using the TPACK standard. The planning domain includes CK, PK, TK, PCK, TPK, TCK, and TPACK. Furthermore, TPACK components were also developed for the implementation, and professional development domains.

2.2 Participant

A total of 108 science teachers who teach at the junior high school level in various schools in Indonesia participated in this study to provide us with perspectives on science teachers' competencies in STEM-ESD learning. They consisted of 83 (74.1%) females and 25 (25.9%) males and came from age groups ranging from under 25 years old to over 45 years old. Participation in the survey was voluntary, random, and anonymous.

2.3 Data Analysis

The Win steps 5.4.1 program used the Rasch model approach to conduct data analysis. Data analysis was conducted to determine the validity and reliability of the STEM-ESD competency instrument for science teachers. The validity test was carried out by testing the validity in the form of overall model fit and dimensionality, as well as the item and personal reliability of the research instruments developed.

3. RESULTS & DISCUSSION

3.1 Designing Science Teacher Competency Indicators for Teaching STEM-ESD

Science teacher competencies in teaching STEM-ESD were developed using TPACK competency standards. The incorporation of TPACK for STEM-ESD learning resulted in a new competency to measure the competency of science teachers in STEM-ESD learning. This competency is divided into three domains, namely, planning, implementing, and professional development domains. The development of the three domains is based on the overall competence of teachers to teach a lesson. They must have the competence in planning, implementing, and developing professionalism to ensure the sustainability of a lesson.

The planning domain in this STEM-ESD competency is a domain that includes the knowledge and planning competencies that teachers have before and after designing tools and supporting STEM-ESD learning. This domain includes seven competency standards that combine TPACK with STEM-ESD learning. These competency standards consist of STEM-ESD Content knowledge (CK), STEM-ESD Pedagogical knowledge (PK), STEM-ESD Technology knowledge (TK), STEM-ESD Pedagogical content knowledge (PCK), STEM-ESD Technological pedagogical knowledge (TPK), STEM-ESD Technological content knowledge (TCK), and STEM-ESD Technological Pedagogical Content Knowledge (TPACK). Each standard is then developed into indicators and sub-indicators. The STEM-ESD CK, STEM-ESD PK, STEM-ESD TK, STEM-ESD TCK, and STEM-ESD TPK standards are divided into one indicator each to see teacher knowledge competencies. Meanwhile, the STEM-ESD PCK and STEM-ESD TPACK standards include teachers' knowledge and skills competencies in designing STEM-ESD learning.

The second domain is implementing, which shows teacher competence in implementing STEM-ESD learning in the classroom. This domain includes the STEM-ESD TPACK standard with its indicators, namely teacher skills in integrating concrete, pedagogic, and technological components in the implementation of STEM-ESD learning. The last domain is the professional development domain, which includes teacher competence in participating in professional development activities and collaborating with fellow teachers, experts, communities, or others related to STEM-ESD learning. This domain includes the STEM-ESD TPACK standard with its indicators, namely the involvement and collaboration carried out by teachers in developing STEM-ESD learning.

The total indicators developed from the STEM-ESD domain and competency standards consist of 9 indicators in the planning domain, 1 indicator in the implementing domain, and 2 indicators from the professional development domain. Planning is the most important part of the preparation and implementation of the learning process, which is an important part of the teacher's professional competence. Teachers are required to have the ability to think about what students should learn, what competencies need to be developed, and what values must be obtained in order to create quality teaching. Good planning is expected to create learning implementation with the right strategy and teacher readiness to master the appropriate material content. So, in STEM-ESD learning, teachers are expected to have good planning competencies.

Implementing learning in the classroom is one form of teacher pedagogic competence. This competency is not only related to how teachers implement learning in the classroom but teachers are expected to be able to improve the quality of learning in the classroom (Guillén-Gámez et al., 2021; König et al., 2021). In the context of STEM-ESD learning, teachers are expected to implement learning, create a learning environment, and conduct assessments that integrate content, pedagogic, and technological components into STEM-ESD learning.

In order to ensure the sustainability of a new learning program, teachers are expected to follow and conduct professional development (Ammoneit et al., 2022; Byrd & Alexander, 2020). Professional development can be seen from teachers' involvement in self-development activities related to STEM-ESD learning. Self-development can be seen from teachers' involvement in attending various trainings, seminars, workshops, or other activities aimed at improving professionalism and being actively involved in teacher communities to improve competencies related to STEM-ESD learning (Acar & Büyüksahin, 2021; Surahman & Wang, 2023). In addition, teachers are also expected to collaborate with fellow teachers, experts, communities, and other parties and share ideas with fellow teachers to develop ideas and disseminate information and learning innovations (Baker-Doylea, 2011; Liou & Bjorklund Jr, 2023; Saat et al., 2021).

3.2 Testing STEM-ESD Competency Indicators with Rasch Modelling

The next step after developing indicators is to conduct a test and measure validity and reliability. The test was conducted with the help of Google Forms and the Likert scale. The pilot test was conducted to measure the quality of the TPACK instrument to measure the STEM-ESD competence of science teachers. The quality of the instrument was tested using Rasch modeling and Unidimensionality, validity, and reliability tests.

Unidimensionality can be shown if the raw variance explained by measures ≥ 20% with a note on the general category of interpretation, which is sufficient if 20-40%, good if 40-60%, and very good if greater than 60%, and if the unexplained variance in 1st to 5th contrast of residuals is less than 15% each (W. Boone et al., 2014). The results of the Unidimensionality test are shown in Table 2.

Table 2: Unidimensionality Test Results

Criteria	Eigenvalue	Observed		Expected
Raw variance explained by measures	117.0403	69.7%		69.3%
Unexplained variance in 1st contrast	6.3408	3.8%	12.4%	
Unexplained variance in 2nd contrast	5.4840	3.3%	10.8%	
Unexplained variance in 3rd contrast	4.3625	2.6%	8.6%	
Unexplained variance in 4th contrast	3.8291	2.3%	7.5%	
Unexplained variance in 5th contrast	2.8036	1.7%	5.5%	

Based on Table 2, the result of raw variance explained by measures is 69.7%, which is classified as a very good criterion. Then the unexplained variance in 1st is 3.8%, unexplained variance in 2nd is 3.3%, unexplained variance in 3rd is 2.6%, unexplained variance in 4th contrast is 2.3%, and unexplained variance in 5th is 1.7%. It can be seen that all results are smaller than 15%. So, it can be concluded that as a unidimensional construct, the TPACK instrument can measure what it is supposed to measure (with no other dimensions outside the construct).

In addition to the unidimensionality test, the validity of each item is also tested to determine which indicators are not suitable (outliers or misfits). The criterion used to determine the validity of items is the mean of infit and outfit mean squares (MNSQ), which have an acceptable range of 0.5 to 1.5. However, 1.6 is still considered acceptable, and <0.5 is not acceptable. Furthermore, the ideal value of the fit criteria is close to 1.00 logits (Andrich, 2018; Bond, 2015). The relatively more stable mean square statistic (MNSQ) is used as the fit criterion for indicator quality assurance. The results of item validity testing can be seen in Table 3.

Table 3: Item Validity Results

Item Code	Outfit MNSQ	Item Code	Outfit MNSQ	Item Code	Outfit MNSQ
P-PCK-A7	0.92	PD-TPACK-A3	1.59	P-PK-1	1.13
P-PCK-A8	0.98	P-PK-2	0.81	P-TPACK-A1	0.72
P-PCK-A5	0.76	P-PCK-A1	0.72	I-TPACK-4	0.67
P-PCK-A3	0.76	P-TCK-2	0.59	I-TPACK-5	0.72
P-PCK-A6	1.00	P-TPACK-A3	0.55	P-TPK-1	0.84
P-PCK-B5	0.81	P-TPACK-B1	0.56	P-TCK-1	0.78
P-PCK-B4	0.87	P-TK-2	1.19	P-TPK-3	0.55
P-PCK-B3	0.94	P-PCK-B2	0.42	P-CK-3	1.43
P-TPACK-A2	0.55	P-TPACK-A4	0.69	P-CK-1	1.13
P-TPACK-B3	0.48	P-CK-4	1.12	PD-TPACK-A4	1.50
P-PCK-A2	0.79	P-TPK-2	0.67	PD-TPACK-B	1.57
P-TPACK-B2	0.47	P-TCK-3	0.49	P-TK-1	1.20
I-TPACK-3	0.71	I-TPACK-2	0.78	PD-TPACK-B1	1.81

NO. ISSN 2987-4564

Item Code	Outfit MNSQ	Item Code	Outfit MNSQ	Item Code	Outfit MNSQ
PD-TPACK-A1	0.94	I-TPACK-7	0.68	PD-TPACK-B4	1.76
P-CK-5	1.76	P-PCK-A4	1.14	P-CK-2	0.85
P-PK-3	0.83	P-PCK-B1	0.93	PD-TPACK-B3	1.88
I-TPACK-6	0.71	I-TPACK-1	0.56	PD-TPACK-A2	2.02

Note:
: misfit/not valid

Based on the results of Table 3, there are 9 indicators whose MNSQ outfit results are declared invalid. The indicator is then revised and retested to ensure its validity. The next test of STEM-ESD competency indicators is to test the reliability of the indicators. Reliability criteria were examined using various indicators, such as Rasch parameters (Bond, 2015; W. J. Boone, 2016) and Cronbach's alpha (α) (Taber, 2018). The Cronbach Alpha value, which shows the interaction between the person and the item, is 0.99, a very good level. Then, the person reliability value is 0.98 as an indicator of the consistency of the respondent's answer, which is acceptable at a very good level. Item reliability is worth 0.73 as an indicator of the quality of the items in the instrument, which is a good category. Based on the Person Table, the average value of INFIT MNSQ is 0.97, and the OUTFIT MNSQ value is 0.95.

Meanwhile, based on the Item Table, the average value of INFIT MNSQ is 0.98 and OUTFIT MNSQ is 0.95. If the provisions are close to 1, it is better because the ideal value is 1. In order for the average person and item to approach the ideal provisions. All reliability results are summarized in Table 4.

Table 4. The Result of the Reliability Test

	Mean MNSQ		Reliability	Alpha Cronbach
	Infit	Outfit		
Person	0.97	0.95	0.98	0.99
Item	0.98	0.95	0.73	

4. CONCLUSION

Based on the explanation above, it can be concluded that STEM-ESD competency indicators are developed based on underlying theories, previous research results, and literature that is in accordance with the competency components. STEM-ESD competencies are divided into 3 domains, namely planning, implementing, and professional development, which are then derived into 7 standards and 9 indicators for the planning domain, 1 standard and indicator for the implementing domain, and 1 standard, which includes 2 indicators for the professional development domain. The indicators were then developed into a questionnaire consisting of 51 questionnaire items. The results of the questionnaire were then identified for validity and reliability using Rasch modeling. The results of item validity are determined based on the MNSQ output value, which shows that 42 questionnaire items are valid. Furthermore, the results of personal reliability show a value of 0.98 as an indicator of the consistency of the respondents' answers, which is acceptable at a very good level. Item reliability is worth 0.73 as an indicator of the quality of the items in the instrument, which is a good category. These results indicate that the competency indicators developed can be used to measure teacher competence, but some questionnaire items need to be improved to get better results. The limitation of this study is the scope of participants involved, which is only junior high school science teachers. It is hoped that this competency can be used to see STEM-ESD competencies in teachers of other subjects so that STEM-ESD learning can not only be applied to science subjects.

5. ACKNOWLEDGMENTS

The author would like to thank Lembaga Pengelolaan Dana Pendidikan (LPDP) for providing financial support to the author in his advanced study process. I also thank the promoter team, who contributed their thoughts in writing this article.

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