The application of fuzzy Delphi method for the development of STEM teaching model

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ABSTRACT

In order to improve the ability of physics student teachers (PSTs) to teach using the science, technology, engineering, and mathematics (STEM) teaching model, this study applied the fuzzy Delphi method (FDM) to determine the constituent items that need to be included in the process of constructing the STEM teaching model according to the characteristics of PSTs. A questionnaire through literature review and expert advice was prepared, which contained 17 items in three constructs, including eight items for cultivating students' abilities, four for teaching strategy design, and five for the expected outcomes. Then, the questionnaire was distributed to 16 experts to collect opinions and suggestions, which were analyzed and ranked using the FDM. The findings showed that all 17 items passed the expert consensus, all the specialist consensus values above 75%, the threshold values (d) ≤0.2, and the fuzzy scores (A) ≥α-cut value=0.5. Within the framework of the study and based on expert consensus, it is necessary for the newly developed STEM teaching model for PSTs to incorporate all 17 items across three constructs. This would optimally enhance the PSTs' ability to employ the STEM teaching model in their teaching instruction.

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1. INTRODUCTION

STEM stands for science, technology, engineering, and mathematics STEM. When STEM education was created in the US as a national development strategy to solve social issues, it attracted much interest on a global scale. The National Science Foundation first used the term "STEM education" in a report on science, mathematics, and engineering at the undergraduate level in 1986. The report's main goal was to pursue and improve higher education in the US because the next generation of Americans could become world leaders in science and technology [1]. After more than three decades of development, STEM education has influenced all areas of university students' learning and lives, and it is now gradually emerging as a strategic option for nations worldwide to implement new education changes in the 21st century [2]. Recent studies have shown that STEM-related degrees increase employment possibilities and labor force wages [3]. In addition, STEM education is viewed as a new approach that encourages problem-solving-driven, interdisciplinary education to help students adjust to the changes brought on by globalization in a changing knowledge-based economy. STEM education is a vital part of today's learning. It promotes equity and access to education and helps students develop the skills and knowledge they need to succeed in the global economy. Developed nations like the US, UK, and Germany have begun to prioritize STEM education at the top of their national goals and programs in response to the need to boost the global core competitiveness of the incoming talent pool [4].

In contrast to university students in other fields, student teachers are more conventional and subservient to traditional ideals, more dependent on obedience, lacking in responsibility, less capable of abstract thought, and more conservative [5]. These characteristics of student teachers also suggest that there would be more significant challenges and reluctance to promote STEM education among student teachers. Since student teachers represent the future of the teaching profession, it will be possible for them to successfully implement STEM in their future teaching professions if they receive STEM education training to broaden their understanding of the subject and strengthen their ability to employ STEM teaching methods. This will make it easier for STEM education to become widely accepted. This is especially prominent for physics student teachers (PSTs) since data indicates that more than 70% of physics educators will be involved in and do work connected to STEM education in China [6]. Therefore, it is essential to implement STEM education among PSTs, and the problems with teacher education for student teachers can be efficiently addressed through STEM education. The development of STEM teaching models has continued since STEM was first introduced. However, there have been few reports of STEM teaching models for PSTs.

Additionally, STEM instruction in physics may help students comprehend the fundamental principles of physics and realize that physics knowledge is founded on fact, is trustworthy, is creative, and is social. Consequently, physics teachers should actively research and practice STEM education to give students more profound and fruitful physics learning experiences. The STEM teaching model can effectively address educational challenges for student teachers majoring in physics or PSTs. Thus, it is essential to establish and develop a set of STEM teaching models specifically for PSTs since the existing STEM teaching models frequently contain several inappropriate components for student teachers. This paper only discusses the items that need to be considered in the design process of a STEM teaching model, and the particular design procedure is discussed separately. This study can improve their interdisciplinary knowledge and abilities, foster their inventive spirit and practical skills, strengthen their instructional design and reflection skills, and facilitate collaboration with teachers from other disciplines by giving elementary and secondary school students a more effective educational experience.

2. METHOD

2.1. Fuzzy Delphi method

Fuzzy Delphi method (FDM) is used in this study, it is an improvement from the Delphi method. The method was proposed by Kaufman and Gupta in 1988. FDM combines fuzzy mathematical theory and the traditional Delphi method [7]. The strength of the fuzzy Delphi technique is its ability to assign priority and position to an element based on the consensus of the experts [8], [9]. The demand items of the STEM teaching model in this study have more uncertainty and unpredictability. Therefore, the FDM method was used to obtain the consistent opinion of relevant experts by consulting professional experts to get the STEM teaching model demand items.

Barrios *et al.* [10] suggest that the appropriate number of experts for the FDM is 10-15. Research by Dawood *et al.* [11] indicate that the number of experts involved in the Delphi method can be as high as 10 to 50. Sixteen experts were selected for this study using purposive sampling techniques, which consisted of STEM education specialists, frontline teachers, secondary school teacher-researchers, and experts in STEM education curricula [12]. The criteria for selection of experts were more than five years of work experience in a particular field [13] and bachelor's degree or higher [14].

2.2. Experts demographic information

Statistical information on the experts is presented in Table 1. Most of them have a bachelor's degree or higher in their field of specialization. All of the professionals have more than five years of work experience combined. The selected experts were education specialists, frontline teachers involved in STEM education, secondary school teacher-researchers, and experts in educational technology and curriculum.

Table 1. Statistical information on experts

Education level		Working experience		Time of STEM		Field of expertise	
Degree	Number	Year	Number	Year	Number	Field	Number
Doctor	10	5-10 years	6	5-10 years	13	STEM teachers	4
Master	4	10-15 years	3	10-15 years	3	Teacher-researchers	5
Bachelor	2	15-20 years	3	Total	16	Curriculum specialists	2
Total	16	>20 years	4			Engineering technologists	5

2.3. Questionnaire development

The questionnaire is adapted based on a literature review, pilot studies and experiences [15]‒[20]. The researchers prepared a fuzzy Delphi questionnaire by reviewing related articles in this study. The questionnaire was given to three experts for validation to get their opinions, and then the questionnaire had to be modified according to their feedback. Five other experts were selected to conduct the reliability test. The questionnaire contains 17 items in three constructs, including eight items for developing students' competence, four items for designing teaching strategies, and five items for improving the teaching skills of PSTs. The fuzzy Delphi questionnaire was pre-tested before its formal use, and the results of the test showed that the Cronbach alpha values of the three parts of the reliability test reached 0.918, 0.863, and 0.874, respectively, indicating that the questionnaire is reliable. The questionnaire was answered using a 5-point Likert scale. The 5-point Likert and fuzzy scoring are shown in Table 2 [7], [16].

Table 2. Five-point Likert score and fuzzy scoring

Likert score	Variable	Fuzzy scoring
1	Strongly disagree	(0, 0, 0.2)
2	Disagree	(0, 0.2, 0.4)
3	Unsure whether to agree or disagree	(0.2, 0.4, 0.6)
4	Agree	(0.4, 0.6, 0.8)
5	Strongly agree	(0.6, 0.8, 1.0)

2.4. Analysis of questionnaire data

Implementing the FDM mainly goes through an expert questionnaire survey, questionnaire assignment into triangular fuzzy numbers, calculation of thresholds and fuzzy scores, and judgement and ranking according to the conditions. Expert opinions were systematically analyzed using Microsoft Excel software [21]‒[23]. The triangular fuzzy number and the defuzzification process are the two primary conditions for the fuzzy Delphi approach. There are two requirements for triangular fuzzy numbers: to begin with, Threshold (d) <=0.2. The expert consensus is established when the result is less than or equal to 0.2 [24], [25]. The calculation formula is as in (1):

$$d(\tilde{m},\tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \quad (1)$$

Where, d is the value of threshold and m, n is triangular fuzzy number, m=(m_1, m_2, m_3) and n=(n_1, n_2, n_3).

Expert opinion unanimity as a percentage is the second requirement of the triangular fuzzy number. If there is more than 75% consensus among the experts, it is acceptable [26]‒[29]. On the other hand, the fuzzification process is to determine the fuzzy score value (A) based on the α-cut value [30]‒[34]. The measurement item is approved if it is fuzzy score (A) is equal to or higher than 0.5 and rejected if it is less than 0.5. Other functions of the fuzzy score (A) include using it as a determinant of element position and priority based on expert consensus. The fuzzy score (A) is determined according to (2).

$$A = \frac{1}{3} * (m_1 + m_2 + m_3) \quad (2)$$

3. RESULTS AND DISCUSSION

3.1. Analysis of expert consensus on developing students' competencies

The questionnaire on developing students' competence needs contains eight items noted as A1-A8. The threshold value (d), expert consensus percentage, defuzzification and item position are shown in Table 3. The threshold (d) for all items was less than 0.2. This result indicates that expert consensus was obtained for all these items [25]. In addition to all items above the value of α-cut=0.5, the specialist agreement percentage indicates that all items are above 75%. The results showed that all eight items in developing student competencies received expert consensus.

3.2. Analysis of expert consensus on teaching model strategies

The essential needs questionnaire regarding teaching model strategies contains four items, which are noted as B1-B4. Table 4 displays the items above threshold value (d), expert consensus percentage, defuzzification, and item position. Threshold (d) ≤0.2 was recorded for every item. This outcome suggests that these things have established a consensus among experts [25]. Every item exceeds 75% according to the expert agreement percentage, and every item's defuzzification value is more than α-cut=0.5. The outcome shows that experts have agreed on the items in STEM teaching model methodologies.

Table 3. Findings of expert consensus on developing student competence

	Item	Condition		Fuzzy score (A)	Position priority	Experts consensus
		Threshold (d)	Experts consensus (%)			
A1	Students can maintain their motivation to learn physics using the STEM teaching model.	0.150	100	0.713	2	Accepted
A2	Students can develop their self-confidence using the STEM teaching model	0.172	94	0.700	6	Accepted
A3	Students can pay attention to physics learning using the STEM teaching model	0.153	100	0.700	5	Accepted
A4	Students can improve their collaboration in physics learning using the STEM teaching model.	0.131	100	0.738	1	Accepted
A5	Students can improve their physics problem-solving skills using the STEM teaching model.	0.150	100	0.713	2	Accepted
A6	Students can facilitate the development of student creativity in engineering using the STEM teaching model.	0.172	94	0.688	8	Accepted
A7	Students can improve their critical thinking using the STEM teaching model.	0.172	94	0.700	6	Accepted
A8	Students can develop their thinking skills using the STEM teaching model.	0.150	100	0.713	2	Accepted

Table 4. Findings of expert consensus on teaching model strategies

	Item	Condition		Fuzzy score (A)	Position priority	Experts consensus
		Threshold (d)	Experts consensus (%)			
B1	STEM education program	0.172	94	0.688	3	Accepted
B2	Project or problem-based learning	0.131	100	0.738	1	Accepted
B3	Inquiry-based learning	0.131	100	0.738	1	Accepted
B4	Digital learning	0.150	100	0.688	3	Accepted

3.3. Analysis of expert consensus on expected outcomes for physics student teachers

The fundamental questionnaire on the needs of the PSTs in terms of expected outcomes contains five items, which are noted as C1-C5. The threshold value (d), expert consensus percentage, defuzzification and item position for the above items are shown in Table 5. Table 5 indicates that threshold (d) <0.2 was recorded for every item. This outcome suggests that professional consensus is now regarding these items [25]. Every item exceeds 75% according to the expert agreement percentage, and every item's defuzzification value is more than α-cut=0.5. The outcome shows that experts have agreed on the items in the expected result for PSTs. The researchers determined the topics of the experts' consensus based on the findings of the analyses conducted using the fuzzy Delphi technique. All the items in each construct were prioritized according to the experts' consensus scores. The items of the STEM teaching model were divided into three constructs: the aspect of developing students' competence, the aspect of STEM teaching strategies, and the aspect of expected outcomes for PSTs, which were 17 items in total. After the analysis using the fuzzy Delphi technique, all 17 items were retained by the experts' approval, which became our preparation of the STEM teaching model's elemental basis.

Table 5. Findings of expert consensus on expected outcomes

	Item	Condition		Fuzzy score (A)	Position priority	Experts consensus
		Threshold (d)	Experts consensus (%)			
C1	Student teachers can use the STEM teaching model to familiarize themselves with the STEM approach.	0.167	94	0.713	2	Accepted
C2	Student teacher can expand their existing methods and approaches using the STEM teaching model.	0.143	100	0.725	1	Accepted
C3	Student teacher can develop their self-confidence in explaining difficult physics learning issues to students using the STEM teaching model.	0.193	94	0.688	5	Accepted
C4	Student teachers can teach physics more effectively using the STEM teaching model.	0.167	94	0.713	2	Accepted
C5	Student teachers can improve teacher educators' teaching skills using the STEM teaching model.	0.150	100	0.713	2	Accepted

3.4. Discussion aspect of developing students' competences

Regarding developing students' competencies, experts agreed that the STEM teaching model should include eight items, as shown in Table 3. Experts for PSTs especially put forward the two items of letting students pay attention to physics learning and keeping students motivated to learn physics; this is because in the process of physics learning, there are more or fewer difficulties, even in the second or third year of the professional physics (four-year undergraduate), are still challenging to learn physics or even have no confidence in learning physics, therefore, through the creation of a new STEM teaching model, to stimulate students' interest in learning physics, and let students actively learn, only in the active participation of students to learn, can achieve good learning results [35]‒[39]. In addition, experts emphasize the importance of collaborative and problem-solving skills in STEM education, arguing that these two competencies contribute to improving physics knowledge acquisition and application and help develop cross-disciplinary integration and adaptability to future societal needs [40].

3.5. Discussion aspect of design of instructional strategies

Regarding the design of teaching strategies, experts agreed that four STEM teaching models could be created: project or problem-based learning, inquiry-based learning, STEM education programs, and digital learning. Project or problem-based learning fits the STEM teaching model well, allowing for interdisciplinary integration and application and promoting a more profound understanding and transformation of knowledge [41]. Experts believe inquiry-based learning is also an effective teaching strategy for STEM [42]. Combined with the characteristics above of PSTs, adopting inquiry-based learning in the STEM teaching model can broadly break student teachers' qualitative thinking and stimulate their innovative spirit.

STEM education programs are another essential element in carrying out STEM teaching. STEM education programs are designed to combine them to form a cohesive learning paradigm based on real-life applications, emphasizing problem-oriented, project-based, inquiry-based and innovation-based approaches and allowing students to apply knowledge and skills from different disciplines to develop their knowledge and skills in the process of solving real-life problems [43], [44]. Besides that, digital learning is also one of the instructional strategies that can be used in the STEM teaching model. Digital learning is a mode that uses digital technology and online resources to support and facilitate learning. Digital learning can help students acquire STEM knowledge and improve STEM literacy. Through digital tools and platforms, such as simulators, virtual labs, and programming software, students can more easily understand and apply STEM concepts to their learning [45], [46].

To summarize, project or problem-based learning, inquiry-based learning, STEM education programs, and digital learning can all be used in STEM teaching mode. They can achieve different teaching effects. We can choose appropriate teaching strategies according to the pre-set teaching objectives to improve learning efficiency and teaching effects and cultivate students' abilities.

3.6. Discussion aspect of improving teaching skills of physics student teachers

Regarding improving the pedagogical skills of PSTs, the experts agreed that the STEM instructional model created through implementation should include five objectives, as shown in Table 5. Research has proven that the STEM teaching model effectively implements physics instruction [47], [48]. PSTs can teach physics more effectively through a STEM approach, improving the quality and effectiveness of physics teaching, enabling students to gain a deeper understanding of physics concepts and principles, acquire physics experimentation and modelling skills, and develop physics thinking and creativity [46], [48]. Through the implementation of the STEM teaching model, PSTs are expected and able to improve their teaching skills and increase their self-confidence in explaining complex physics learning issues to students through the learning of STEM methods so that they can better cope with the difficulties and challenges encountered in physics teaching, such as how to explain abstract and complex physics concepts to students [49].

4. CONCLUSION

In order to improve the ability of PSTs to teach using the STEM teaching model, this study determines the constituent items that need to be included in the construction process of the STEM teaching model by consulting experts using the FDM according to the characteristics of PSTs. The constituent items were divided into three constructs: the development of students' competence contained eight items, the design of teaching strategies contained four items, and the improvement of teaching skills of PSTs contained five items totaling 17 items. The researcher identified the items agreed upon by the experts and prioritized the items in each construct based on the expert consensus scores. The study results showed that all 17 items passed the expert consensus. On the developing students' competencies section, A4's fuzzy score (A)=0.738 ranked first in this section, A1, A5, A8 with fuzzy score (A)=0.713 ranked 2nd-4th respectively, A2, A3, A7 with fuzzy score (A)=0.700 were ranked in the 5th-7th positions, and A6 fuzzy score (A)=0.688 ranked in the 8th position. In the teaching model strategies section, B2, B3 with fuzzy score (A)=0.738 ranked 1st-2nd in this section and, B1, B4 with fuzzy score (A)=0.688 ranked 3rd-4th respectively. On the expected outcomes for PSTs section, C2 with fuzzy score (A)=0.725 ranked first in this section, C1, C4, and C5 fuzzy score (A)=0.713 ranked 2nd-3rd, C3 fuzzy score (A)=0.688 ranked 4th-5th respectively. According to the experts' consensus, the newly developed STEM teaching model for PSTs needs to contain these 17 items of the constructs. Therefore, the PSTs' ability to teach using the STEM teaching model can be developed to the greatest extent possible. As a next step, the researchers will combine the findings of the expert consensus items to design a STEM teaching model suitable for PSTs and test and validate it in real classrooms.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest. The authors have no potential conflicts of interest to declare that are relevant to the content of this article.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study. These consent documents are available from the corresponding and main authors [SWT and ZZ], upon request.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant institutional policies and has been approved by the authors' institutional review board via Universiti Pendidikan Sultan Idris (UPSI). Approval of human research ethics committee of UPSI are available from the corresponding and main authors, [SWT and ZZ], upon request.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding and main authors [SWT and ZZ], upon reasonable request.

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