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MODELLING OF PCK COMPETENCY OF PROGRAMMING TEACHERS THROUGH FUZZY DELPHI METHOD (FDM)

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Abstract

It is not surprising to hear secondary school students and undergraduates incessantly complaining about their difficulties in learning programming. Obviously, such difficulties may be attributed to a myriad of factors. As such, this entails examining programming teachers' competency in teaching the subject matter. The objective of this study is to explore and validate the elements of pedagogical and content knowledge (PCK) competency of programming teachers. In this research, the researchers first reviewed the current literature and a needs analysis study to explore potential elements of competency of programming teachers. Then, the researchers carried out a survey involving 22 academic members to elicit their opinions on such competency elements. Finally, the researchers performed the Fuzzy Delphi Method to validate the experts' opinions. The validation analysis highlighted 23 elements of competency, with all attaining threshold (d) values of less than 0.2 and percentages of agreement of more than 75%. Effectively, these findings strongly suggest that the validity of such elements of competency of programming teachers is high, with which a model of competent programming teachers could be developed. With such a model, programming teachers would be able to select and apply appropriate teaching strategies to help them teach programming to their students more effectively

Keywords: Competency, competency model, programming teacher, Fuzzy Delphi Method (FDM).

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1. Introduction

It is not surprising to hear secondary school students and undergraduates incessantly complaining about their difficulties in learning programming. Obviously, such difficulties may be attributed to a myriad of factors. Hence, studies focussing on why students are not doing well in learning the subject matter have been earnestly carried out. Nonetheless, the majority of the studies has only focussed on the role of programming teachers in the classroom (Rinderknecht, 2014; Selvi, 2010) but not on their teaching competency (Selvi, 2010). Further compounding the problem is that a model that can precisely describe programming teachers' competency is seriously lacking (Seitz & Zendler, 2015). Therefore, the imperative to develop such a model that can help define the key elements of competency of programming teachers must be duly addressed (Nor Masharah, Muhammad Modi, & Sulaiman, 2017). Undisputedly, the preparation of competent programming teachers is a challenging task, given the many training issues that have to be addressed (Yadav, Gretter, Hambrusch, & Sands, 2016). Many scholars assert that programming teachers need to improve not only their content knowledge but also their teaching skills, with which they will be able to teach programming subject more effectively and efficiently. In this regard, more efforts are required to examine teachers' competency in teaching programming rather than to merely focus on their role in the classroom.

The implementation of computer science and programming subjects in the secondary schools is part of the Malaysian government's initiatives to produce highly skilled, knowledgeable workforce that is needed in this competitive world. In particular, programming is one of the important skills that can help our nation to produce cutting-edge applications or solutions for many industries, such as manufacturing, computer, and construction, among others. However, learning programming can be quite daunting to many students due to the abstract concepts and complicated algorithms of the subject matter. To overcome such problems, programming teachers must develop the necessary skills and knowledge to help students to learn programming with higher efficacy (Killen, 2005; Saeli, Perrenet, Jochems, & Zwaneveld, 2011; Teh Faradilla, Zaid Mujaiyid Putra, & Juliana, 2013). With improved teaching techniques, students will be able to learn programming logics – which is the main problem faced by students – with greater efficacy.

Clearly, the use of effective teaching techniques can help guide students to develop strong logical thinking or reasoning skills. More importantly, such techniques must provide students with sufficient opportunities to test their understanding, explain the difference between surface and deep understanding of important concepts, and show how deep understanding can help in solving programming problems. In view of the above concerns and problems, programming teachers must possess a sound knowledge of the subject matter to ensure that they can impart the required knowledge to the students effectively. To facilitate such transfer of knowledge, a model of competency of programming teachers is urgently needed. Hence, this study was carried out with the main aim of determining and validating the elements of PCK competency of programming teachers.

2. Problem Statement

In general, the definitions of competency include various terms in accordance with the specific aspects of job requirements, measurements of performance, and capability of workers or personnel to perform their duties and responsibilities. As such, members of an organization must have adequate

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competency to ensure they would be able to perform their duty productively. Likewise, programming teachers should possess sufficient competency to ensure their students will receive high quality teaching. From the teaching standpoint, competency refers to the mastery of skills of teachers in teaching a particular subject matter that enables them to achieve a set of prescribed learning outcomes using appropriate strategies (William, 1974). Similarly, Irena, Anita, and Zane (2006), defined competency as a set of knowledge, skills and experience necessary for learning activities. Alternatively, the term "competence" refers to teachers' ability to control the teaching process using existing knowledge and skills.

Irrespective of such diverse definitions, the importance of sound competency in teaching cannot be overstated, because it determines the quality and performance of teachers in teaching a particular course or subject. In this respect, competent teachers are those that have sound ability to deliver and discuss learning contents of a particular topic effectively, with which they can help their students to develop a strong understanding of the important principles or concepts being learned. Simply put, teachers need to possess all the necessary elements of competency to provide quality teachings for their students (Saedah & Mohammed Sani, 2012). Furthermore, teachers' competency in preparing quality lesson plans is also an essential factor in determining the success of a teaching session (Copriady, 2014). Clearly, teaching competency encompasses a host of factors, including the planning, implementation, and evaluation of school curriculum and standards, which together will have a huge impact on the quality of teaching (Yu, Luo, Sun, & Strobel, 2012).

Shulman (1986) defined pedagogical content knowledge (PCK) as the combination of knowledge of the content and the pedagogy related to the learning and teaching of a subject or a course. Essentially, the content knowledge of the subject matter refers to the "knowledge of truth" to be learned by or taught to students. Based on the PCK model conceptualized by Shulman and Grossman (1988), the content knowledge of a particular subject has two main constituents, mainly substantive and syntactic knowledge. Substantive knowledge includes key facts, concepts, principles, structures, and explanatory frameworks of the subject. In contrast, syntactic knowledge refers to the rules of evidence and truth of a particular discipline and how new knowledge is introduced and accepted in learning, which is precisely about knowing the specifics of the subject. Pedagogical knowledge refers to deep knowledge about the processes, practices, or methods of teaching and learning, and how it integrates all these elements systematically to achieve the overall educational goals, values, and goals. Alternatively, pedagogical knowledge can be viewed as a generic form of science that deals with all issues of student learning.

Many studies of training of teachers indicate that trainee teachers have not gained significant development in PCK, thus raising concerns about their ability to provide quality teaching for students. According to Armoni (2011), having strong PCK is extremely important as it represents teachers' knowledge of how to identify the most appropriate teaching strategies by which they can transfer their knowledge to their students through meaningful learning experiences, thus enabling their students to attain sound understanding of the subject matter. In this respect, there is a difference between knowing the knowledge (content knowledge) and teaching (pedagogical knowledge). More specifically, the knowledge of contents of a particular subject refers to the "knowledge of the truth" of what is being taught or learned, encompassing the key facts, concepts, principles, structures, and explanatory frameworks of the subject (Shulman, 1987).

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For the programming subject, important elements of the content knowledge include loops, data structures, arrays, problem-solving skills, decomposition, and algorithm parameters (Saeli, Perrenet, Jochems, & Zwaneveld, 2012). Research findings of a study by Lahtinen, Ala-Mutka, and Järvinen (2005) indicate that the teaching of programming elements (e.g., recursive, guidance and referral, abstract data, error handling, and library) is challenging as students have to struggle to learn such concepts. Together, such programming elements represent the core contents of the subject matter, which students must fully understand before they can begin to solve programming problems. For this study, the researchers focused on all concepts, techniques, and disciplines of programming and pedagogical aspects of teaching programming.

Pedagogical knowledge refers to the knowledge and understanding of the processes, practices, or methods of teaching and learning, with which teachers employ to attain the desired educational goals, values, and outcomes. From the teaching perspective, this type of knowledge is a generic science that deals with all issues of student learning. For teachers to develop strong pedagogical knowledge, they need to fully understand the cognitive developments of students and social learning theories. Armed with sound pedagogical knowledge, teachers will be able to fully understand how students construct knowledge, acquire skills, and develop positive habits and dispositions toward learning, such that the former can guide the latter to learn efficaciously. In fact, teachers should have sound pedagogical and content knowledge, the relation of which is closely intertwined that can have a huge impact on teaching. Furthermore, teachers must know how to transfer their knowledge of programming to their students in a simple, effective manner. According to Yusminah and Effandi (2015), PCK also includes teachers' ability to determine the level of difficulty of a certain topic and the potential misconceptions, such that the teachers will be able to select the most appropriate teaching method to deal with such a situation. In fact, the need to develop sound PCK seems to grow more and more imperative as several studies, including Armoni's (2011), indicate that the quality of teaching of some teachers has been questioned by some scholars due to their poor PCK, which may adversely affect student learning.

For this study, the focus was on the teaching competency of programming teachers in imparting programming knowledge to students. Thus far, a majority of studies have largely focussed on the preparation of computer science teachers (Gal-Ezer & Zu, 2013; Margaritis et al., 2015 ; Orit, Judith, & Noa, 2010) and the aspects of content knowledge of teachers (Driel, Verloop, & Vos, 1998; Ioannis & Charoula, 2013; Saeli et al., 2011). In addition, several researchers have conducted studies on the quality of teaching of programming and teachers' perspective of quality teaching of computer programming (Armoni, 2011; Kushan, 1994; Saeli et al., 2011; Schulte, 2013). Arguably, the required PCK of programming teachers may be different from other subject teachers, because of the highly abstract and complex nature of the programming subject (Erdogan, Aydin, & Kabaca, 2004).

Notably, teaching programming is highly dependent on and influenced by teachers' experience and their teaching approaches (Saeli et al., 2012). Thus, with sound PCK, programming teachers will be able to identify and apply appropriate teaching strategies in teaching specific programming topics (Nor Masharah, Muhammad Modi, & Sulaiman, 2014; Saeli et al., 2011; Teh Faradilla et al., 2013). Such contention is not surprising, given that there is a significant difference between knowing a subject (content knowledge) and how to teach it (pedagogical knowledge). Similarly, Killen (2005) draws the same parallel, asserting that

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programming teachers need to focus on the "knowledge of the subject", "how students learn", "how to teach the topic", and "how to teach a topic to students in a particular context". In other words, teachers must have well-developed PCK to help them deal with various pertinent questions, such as "why they need to teach programming?", "which programming topics are difficult to teach?", "how programming can be best taught?", and "what are the difficulties in learning programming?"

Clearly, selecting the most appropriate teaching methods of programming relies on a host of factors, such as teachers' knowledge, their understanding of contemporary learning theories and best teaching practices, and potential problems in teaching certain programming topics. Moreover, the diversity of programing topics, some of which are extremely difficult to teach or to learn, may further entrench such teaching difficulties. Therefore, programming teachers must put in more efforts and seek appropriate measures to improve their teaching. Failure to take the necessary actions in determining the most appropriate teaching methods (Jenkins, 2002) or teaching strategies (Gomes & Mendes, 2007) can result in students having difficulties in learning the subject matter. Hence, it is important that future programming teachers must undergo systematic and holistic training to help them develop sound PCK competency. Equally important is that such training has to be based on sound guidelines or frameworks (Nor Masharah, Muhammad Modi, & Sulaiman, 2016).

3. Research Questions

The research question work on identification and verification on the element of PCK competency of programming teachers.

1. What is the elements of content knowledge competency based on Fuzzy Delphi Method (FDM)?
2. What is the elements of pedagogy knowledge competency based on Fuzzy Delphi Method (FDM)?

4. Purpose of the Study

The main objective of this research was to identify and validate the elements or components of competency, which helped develop a model of programming teachers' competency. A critical review of relevant literature was carried out to examine teachers' PCK in teaching computer science and programming, revealing a number of elements of PCK competency. Then, a group of experts, who had vast teaching experience, were surveyed to validate such elements.

5. Research Methods

The researchers used the Fuzzy Delphi Method (FDM) to obtain a consensus of opinions (which were elicited from a survey) from the experts. Initially, Murray, Pipino, and Gigvh (1985) proposed this method, and later Kaufmann and Gupta (1988) revised it based on the fuzzy set theory. The revision has improved the method considerably, making its linguistic description and decision making more robust and precise (Habibi, Sarafrazi, & Izadyar, 2014). Moreover, according to Norlidah, Fuziah, Mohd Nazri, and Dewitt (2015), FDM efficiently helps obtain a consensus of experts' opinions without the need of too many cycles. In fact, a recent study has demonstrated that FDM was able to obtain a reliable consensus from

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experts in a single round, which helped produce fast and accurate results (Mohd Ridhuan, Saedah, Zaharah, Nurulrabihah, and Ahmad Arifin, 2014).

In essence, the fuzzy rules have two main components, namely the Triangular Fuzzy Number and the Defuzzification Process. Such a number is used to generate a measurement scale that is similar to the Likert scale, which translates variables to fuzzy numbers. In this research, the researchers used 5-point Likert scales, which were based on a spectrum of responses (i.e., agreement and disagreement), ranging from "1" (strongly disagree) to "5" (strongly agree). Essentially, triangular fuzzy number has three values, namely m1, m2, and m3, which refer to the lowest value, the most reasonable value, and the highest value, respectively (see Figure 1).

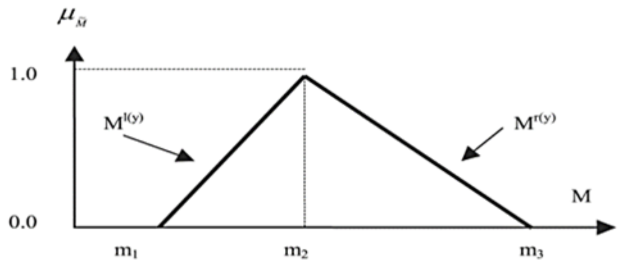

Figure 01. The values of Triangular Fuzzy Number

Table 1 shows the responses, Likert scales, and triangular fuzzy number used in the FDM analysis.

Table 01. The responses, Likert scales, and triangular fuzzy numbers

Response	Likert Scale	Triangular fuzzy number
Strongly disagree	1	0.00, 0.00, 0.20
Disagree	2	0.00, 0.20, 0.40
Moderately Agree	3	0.20, 0.40, 0.60

From Table 1, each Likert scale of responses was assigned with three values of the triangular fuzzy number, with the highest value indicating the highest accuracy. The data were then processed to obtain the Fuzzy values (n1, n2, and n3), Fuzzy average values (m1, m2, and m3, from which threshold values were calculated), percentages of agreement of experts, and defuzzification values. To determine that the experts had reached a strong consensus, the threshold values (d) must not be greater than zero ("0"). If not, the researchers had to perform another round of survey to determine whether the questionnaire items were relevant or not (Cheng & Lin, 2002). The threshold values were calculated based on the formula as shown in Figure 2.

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

Figure 02. The formula for obtaining the threshold values

Additionally, the FDM helped define the acceptable percentage of agreement of experts to the overall item or individual item. If the calculated percentage was greater than 75% and the defuzzification

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value of each questionnaire item was greater than 0.5, the consensus of the experts' opinions was deemed strong (Cheng & Lin, 2002; Chu & Hwang, 2008)..

6. Findings

For this research, the process of validating the elements of competency of programming teachers was carried out with the use of the FDM. Initially, such elements were identified through a review of the current literature, contents analysis of the programming subject, and discussions with relevant practitioners. Specifically, the researchers recruited 22 experts to help conceptualize the appropriate elements of competency. Later, questionnaire items with relevant statements were formulated to elicit experts' opinions on the validity of such elements. The FDM was then used to analyse and validate the experts' opinions, yielding 23 essential elements of PCK competency. Table 2 and Table 3 summarize the elements of content knowledge competency and of pedagogical knowledge competency, respectively.

Table 2 shows that there are 12 elements of content knowledge competency of programming teachers, which they should master to become competent in teaching programming.

Table 02. The elements of content knowledge competency

	Content Knowledge Competency
1.	Mastery of Control Structures
2.	Mastery of Operations / functions
3.	Mastery of Methods
4.	Mastery of Algorithms
5.	Mastery of Variables
6.	Mastery of Constants
7.	Mastery of Parameters
8.	Mastery of Data Structures
9.	Mastery of Decomposition (problem solving)
10.	Mastery of Arrays
11.	Mastery of Logic Thinking
12.	Mastery of syntaxes of programming languages

The elements of pedagogical knowledge relate to various aspects of teaching, such as pedagogical practices, knowledge of learners, learning difficulties, conceptual misconceptions, types of information, and understanding of appropriate guidelines, among others. Table 3 shows that there are 11 elements of pedagogical knowledge competency of programming teachers.

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Table 03. The elements of pedagogy knowledge competency

	Pedagogy Knowledge Competency
1.	Mastery of misunderstanding of concepts in programming
2.	Mastery of learning design that is appropriate for the level of student understanding
3.	Mastery of interesting activities for students
4.	Mastery of samples or appropriate activities to challenge students' proficiency level
5.	Mastery of examples or analogies that helps improve learning of programming
6.	Mastery of management of students teamwork project
7.	Mastery of methods for assessing programming assignments
8.	Mastery of deductive approaches and their applications to topics with varying difficulties
9.	Mastery of inductive approaches and their applications to topics with varying difficulties
10.	Mastery of formulation of questions to test students’ programming skills
11.	Mastery of utilization of appropriate teaching tools for teaching

6.1. Fuzzy Delphi Analysis

The researchers performed the FDM analysis on the experts’ opinions, which had been previously collected from a survey. Based on this analysis, the level of consensus among the experts was determined. The responses of experts to questionnaire items were rated along 5-point Likert scales and were then transformed into fuzzy sets. For this study, the principle used to determine a strong consensus of opinions was based on Cheng and Lin's (2002) and Chu and Hwang's (2008) recommendations, who proposed that the percentages of agreement among the experts should exceed 75%. Table 4 shows the findings of the FDM analysis.

Table 04. The fuzzy weights, threshold values, and percentages of the content knowledge competency

Item of competency		**Fuzzy weight**	**Threshold value, d**	**Percentage of agreement**
1.	Mastery of Control Structure	0.573, 0.773, 0.973	0.072	86%
2.	Mastery of Operations / functions	0.536, 0.736, 0.936	0.133	100%
3.	Mastery of Methods	0.536, 0.736, 0.936	0.133	100%
4.	Mastery of Algorithms	0.545, 0.745, 0.945	0.121	100%
5.	Mastery of Variables	0.518, 0.718, 0.918	0.148	100%
6.	Mastery of Constants	0.464, 0.664, 0.864	0.189	91%
7.	Mastery of Parameters	0.491, 0.691, 0.891	0.197	86%
8.	Mastery of Data Structure	0.545, 0.745, 0.945	0.121	100%
9.	Mastery of Decomposition (problem solving)	0.573, 0.773, 0.973	0.072	86%
10.	Mastery of Arrays	0.500, 0.700, 0.900	0.181	91%
11.	Mastery of Logic Thinking	0.582, 0.782, 0.982	0.050	91%
12.	Mastery of syntax of programming	0.509, 0.709, 0.909	0.151	100%

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As shown, the threshold values (d) of items of the content knowledge competency were less than 0.2. The same analysis revealed the percentages of agreement of experts to all items were more than 75%. Together, the above findings indicated that the experts had reached a strong consensus of opinions, thus validating all the 12 elements of such competency (see Table 4).

Table 05. The fuzzy weights, threshold and percentages of the pedagogical knowledge competency

Item of competency		Fuzzy weight	Threshold value, d	Percentage of agreement
1.	Mastery of misunderstanding of concepts in programming	0.491, 0.691, 0.891	0.151	100%
2.	Mastery of learning design that is appropriate for the level of student understanding	0.482, 0.682, 0.882	0.164	95%
3.	Mastery of interesting activities for students	0.473, 0.673, 0.873	0.177	91%
4.	Mastery of samples or appropriate activities to challenge students' proficiency level	0.509, 0.709, 0.909	0.151	100%
5.	Mastery of examples or analogies that helps improve learning of programming	0.473, 0.673, 0.873	0.159	95%
6.	Mastery of management of students teamwork project	0.418, 0.618, 0.818	0.101	81%
7.	Mastery of methods for assessing programming assignments	0.491, 0.691, 0.891	0.167	95%
8.	Mastery of deductive approaches and their applications to topics with varying difficulties	0.464, 0.664, 0.864	0.170	91%
9.	Mastery of inductive approaches and their applications to topics with varying difficulties	0.445, 0.645, 0.845	0.150	91%
10.	Mastery of formulation of questions to test students’ programming skills	0.509, 0.709, 0.909	0.151	100%
11.	Mastery of utilization of appropriate teaching tools for teaching	0.445, 0.645, 0.845	0.150	91%

Similarly, the threshold values (d) of all items of the pedagogical knowledge competency and percentages of agreement of experts’ opinions were less than 0.2 and more than 81%, respectively. Again, such promising findings suggest that the consensus of opinions reached by the experts is high (Cheng & Lin, 2002), thus validating all the 11 elements of such competency (see Table 5). Clearly, the above findings indicate that all the 23 elements of the PCK competency of programming teachers are valid and relevant. On closer examination, the defuzzification values of the elements of content knowledge competency were impressive, ranging from 0.05 to 0.19, which further reinforced their validity. Likewise, the defuzzification values of the elements of pedagogical knowledge competency were equally remarkable, ranging from 0.10 to 0.17, which further strengthened their validity.

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7. Conclusion

The literature is replete with many studies indicating that students have been overwhelmed with problems in learning the programming subject or course, as many of its learning topics are highly abstract and complex. Such predicament is not surprising, as many studies have shown that there is a plethora of challenges faced by students in learning the subject matter. Clearly, for students to fully grasp the importance of knowing the basic principles of programming, teachers need to play a pivotal role during instructions by exposing students to various learning activities, such as discussions, experimentations, and demonstrations, among others. To accomplish this, programming teachers must have strong, well-developed PCK competency. As such, this study was undertaken to identify and validate the elements of PCK competency of programming teachers.

A survey involving a group of experts was carried out to elicit their expert opinions on such competency elements. The survey revealed 23 elements of competency, of which there were 12 elements of content knowledge competency and 11 elements of pedagogical knowledge competency. FDM analysis was then performed to ascertain the level of agreement of opinions of the experts. The analysis showed that all elements of such competency attained defuzzification values of less than 0.2 and percentages of agreement of more than 75%. Together, such findings indicated that a strong consensus of opinions was reached by all the experts with regard to the validity of the elements of PCK competency. Thus, a model of programming teachers' competency consisting of the 23 validated elements could be developed to help improve the current teaching practice.

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