REVIEW ARTICLE

Environmental Science, Technology, Engineering, and Mathematics Pedagogical Content Knowledge: Teacher's Professional Development as Environmental Science, Technology, Engineering, and Mathematics Literate Individuals in the Light of Experts' Opinions#

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ABSTRACT

This study is based on a Delphi study on environmental literacy which is related to both teachers professional development and environmental science, technology, engineering, and mathematics ($^{E+}$STEM) literacy. In the light of the expert opinions, the goal is to determine what teachers should do to develop their experiences and qualifications as $^{E+}$STEM literate individuals. In this study, a "mixed method" research design, in which both qualitative and quantitative methods are involved, is used to reveal the expert opinions. The exploratory sequential design, which is one type of mixed method research, is used. In the first step of the Delphi study, qualitative data are collected about teachers' professional development. After analyses of data in the first step of Delphi study, the quantitative form is developed for second step of the Delphi study. Finally, after analyses of the data in the second step, the final quantitative form (3rd step) is prepared again. It is performed in three consecutive steps in Delphi study. The sample consists of the 45 experts who initially accepted to participate in the study. 20 of the 45 experts participated in the first step Delphi. The number of participants in the second and third Delphi study, respectively, is 44 and 26, respectively. It is concluded that there is a consensus about "having and updating content knowledge about environmental issues," "following the development of environmental technologies, and applying them in class." There is additional agreement about "having and developing pedagogical competencies for the development of teachers" experiences and qualifications as $^{E+}$STEM literate individuals. It is suggested that the concept of "environment" should be integrated into the framework of "STEM pedagogical content knowledge (PCK)" for teacher's professional development. By this means, a new educational and environmental concept, $^{E+}$STEM-PCK, would be incorporated in teacher education.

KEY WORDS: environmental science, technology, engineering, and mathematics literacy; Delphi study; mixed-methods; professional development; pedagogical content knowledge; stem education; science education

INTRODUCTION

In the 1990s, the National Science Foundation (NSF) began using "SMET" as shorthand for "science, mathematics, engineering, and technology;" however, this abbreviation has been changed to science, technology, engineering, and mathematics (STEM) since it causes conceptual confusion (Sanders, 2009). It is seen that the STEM concept, which is increasing in popularity in Europe nowadays, emerged as MINT in Germany. The term "MINT" is an acronym for "mathematics, information technology, science, and technology" (Wood, 2011). While STEM education has been around for a long time, it is the importance of this concept that has been emerged recently for legislators and educational administrators (White, 2014).

Importance of STEM Education in Science Education

STEM education is increasing in its importance as one of the main concepts in science education. STEM is an ever-growing part of our life. When it is examined the events and things that occur in our daily lives, it is seen that these are related to STEM. Therefore, some educators believe that individuals might be better for jobs in STEM fields with STEM education (Brown et al., 2011). STEM education has the opportunity to integrate four disciplines into coherent teaching and learning paradigm, as well as, providing students with the best opportunities to make sense of the world holistically (Lantz, 2009). STEM education is also important for the development of individuals. STEM education offers students the opportunity to realize their own potential, improve and strengthen self-efficacy, and STEM education supports them through their social and academic integration (Elster, 2014). Moreover, STEM education focuses on students' development of the following abilities (Flanders State of Art, 2018):

1. Awareness of each component in STEM,
2. Problem-solving activities,
3. Researching and designing in a skilled and creative manner,
4. Thinking and reasoning, modeling, and abstracting,
5. Strategically using and developing technology,
6. Acquiring an insight into the relevance of STEM,
7. Obtaining and interpreting information and communicating about STEM,
8. Cooperative learning and teamwork,
9. Acquiring 21st century skills,
10. Developing innovation skill.

Today, many countries continue to make reforms both in industry and education to address the needs of the world. In the area of science education, one of the reforms is to STEM education. Policymakers believe that STEM education is one of the concepts that are important for the industrial sector to improve the quality of the workforce. While the quality of the workforce is enhanced with STEM education, we should also pay attention to environmental literacy to help conserve natural resources.

Environmental Literacy as a Core Concept in Science Education

Throughout its development, environmental literacy has been a key concept in science education. Studies on an environmental literacy framework have increased in recent years. In the Belgrade Charter (1975), environmental education had six components including awareness, knowledge, attitude, skills, evaluation ability, and participation. According to the Tbilisi Declaration (UNESCO, 1977), environmental education included: Knowledge, attitude, skills, and participation. With the development of environmental education, the concept of environmental literacy was clarified, and it had four major components knowledge, skills, affects (sensitive and attitudes), and behavior (personal investment, responsibility, and actions). Whereas in the light of PISA data, Kaya and Elster (2017a; 2017b) proposed that the concept of environmental literacy involves awareness and responsibility toward the environment and the development of environmental behaviors.

Based on the historical development of environmental literacy, environmental literacy is "basically the capacity to perceive and interpret the relative health of environmental systems and take appropriate action to maintain, restore, or improve the health of those systems" (Roth, 1992. p. 10). According to Minner and Klein (2016), environmental literate individuals are able to understand ecosystems and how they function, able to think critically about effects of humans on ecological function and environmental problems, aware of the importance of natural phenomena and biodiversity in natural settings, and able to participate in action planning for themselves and their community to tackle environmental issues.

In another definition, environmental literacy is described as "the ability to make informed decisions about issues affecting shared natural resources while balancing cultural perspectives, the economy, public health, and the environment" (North Carolina Department of Environmental Quality, 2017. p. 7). Moreover, environmental literacy "involves an awareness and knowledge of the interrelationships among life forms and natural systems; understanding of ecological, social, economic, and cultural processes, and issues; and knowledge and skills needed to make informed decisions and to become environmental stewards" (Tennessee Department of Environment and Conservation, 2012. p. 1). In a similar definition, environmental literacy is seen as "an individual's understanding, skills, and motivation to make responsible decisions that consider his or her relationships to natural systems, communities, and future generations" (Oregon Environmental Literacy Plan, 2010, p. 4).

Consequently, the literature review shows there is no universally accepted definition of environmental literacy (Loubser et al., 2001; Morrone et al., 2001; Gayford, 2002). Even though the concept of environmental literacy has been used for many years, it is difficult to explain due to its complexity (Kaya and Elster, 2017b). Nevertheless, there is a need for further research on the framework of the concept and its application in the curriculum to meet present and future expectations. Therefore, it is necessary to reveal the framework of environmental literacy based on expert opinions.

Significance of "Environmental STEM (E+STEM) Literacy" in Science Education

Asunda (2012) argue that there is a need for a high-quality STEM-educated workforce for our 21st century economies. These developing economies create pathways for a wide range of interesting and exciting career opportunities. The aim of STEM is to have knowledge in science, technology, mathematics, and engineering to achieve STEM literacy. STEM literacy is important for individuals who will enter the labor market, as it is one of the core competencies of 21st century workers (Techakosit, 2018). Therefore, STEM literacy first requirement is to have an interest and basic understanding of STEM-related fields (Sutter, 2014). The purpose of STEM is as follows (Zollman, 2012):

- To resolve societal needs for new technological and scientific advances;
- To resolve the economic needs for national security; and
- To resolve personal needs to become a fulfilled, productive, and knowledgeable citizen.

To meet these goals, STEM-literate individuals are able to describe, explain, and predict the outcome of natural phenomena, comprehend scientific articles and pieces presented in popular press and media, as well as have the ability to form their own opinion about the validity of scientific claims being made in the press and media (Sutter, 2014).

Nowadays, the content of STEM is continuously widening. Therefore, STEM includes not only STEM but also the environment, economics, and medicine (Zollman, 2012). In this study, "E+STEM literacy" concept is used to emphasize the importance of the relationship between environment and STEM literacy. E+STEM literacy is as follows:

- To have basic knowledge on environmental issues and STEM-related fields,
- To understand the integration of environmental into STEM fields,
- To deal with environmental issues or problems with an interdisciplinary (STEM) point of view and try to find solutions in the matter,
- To have the skills to evaluate data and draw conclusions to form one's own opinion.

Addressing the needs for a high-quality STEM workforce in future industries might be based not only on STEM literacy but also on environmental literacy. Therefore, environmental literacy should be integrated into STEM fields, as well as into STEM education.

Why Do We Need the Concept of "Environment" in the Stem Education?

It is predictable that technology will develop faster with the industry 4.0 revolution. This means, unfortunately, that existing natural resources may be exhausted. Therefore, future generations should be aware of the necessity of environmental protection while developing and using technology. This awareness may contribute to the reduction of daily waste as well as commercial waste especially industrial waste (such as waste batteries, electrical, and electric materials). For example, in Germany, it has been reported that the total amount of waste is increasing continuously especially since 2012 (Federal Ministry for the Environment, 2018). Preventing the continuous increase of waste means the protection of existing resources. We have the obligation to educate future generation as environmentally conscious individuals, taking into consideration the harms that science and technology have on the environment (Aydeniz, 2017). For this reason, the importance of "environment" in STEM education should be revealed. Teachers and researchers have a great responsibility in this regard because, during STEM education, it is necessary for practitioners to reveal the importance of the environment and how to integrate the environmental issues into STEM education.

The Effect of Pedagogical Content Knowledge (PCK) and Teachers' Professional Development

Teachers' professional experience, teaching skills, and disposition influence the training of qualified environmentally literate individuals (Kaya and Elster, 2018). In general, teachers gain their professional experience in a process that begins with pre-service training and continues with in-service training (Kaya and Gödek, 2016). Educators should focus on teacher training and professional development so that teachers can comfortably teach and integrate environmental subjects in their classes (National Environmental Education Advisory Council, 2015). It may not be possible to educate individuals with 21st century skills without the contribution of a qualified teacher (Pacific Policy Research Center, 2010). Moreover, professional development needs a multi-level approach to educate effectively students for environmental literacy (Ever, 2012). Institutions with responsibilities for teacher training and professional development should support the development of teachers' environmental content knowledge, pedagogical skills, interdisciplinary work, teaching approaches, effective assessment practices, and ability to use innovative technology. Therefore, the concept of PCK introduced by Shulman (1986) remains important (Table 1 and Figure 1). In the view of Shulman (1986), PCK:

> Goes beyond knowledge of subject matter *per se* to the dimension of subject matter knowledge for teaching.… PCK also includes an understanding of what makes the learning of specific topics easy or difficult: The conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons (p. 9).

PCK is influenced by three different component knowledge areas: Subject matter knowledge, pedagogical knowledge, and knowledge of context (Abell, 2007).

The development and change of PCK and its framework continue to meet the expectations of the 21st century and beyond. One of the most concrete examples is technological PCK (TPCK) introduced by Mishra and Koehler in 2006, which integrated technology with PCK and recognized the

Table 1: Components of environmental education and literacy (Adapted from Kaya and Elster, 2017b)

Environmental education objectives (Charter, 1975)	Tbilisi declaration for environmental education (UNESCO, 1977)	Environmental literacy (Roth, 1992)	Environmental literacy (Kaya and Elster, 2017a; 2017b)
Awareness knowledge	Knowledge	Knowledge	Environmental awareness
Attitude	Attitude	Sensitivity, attitudes and values, personal investment and responsibility	Environmental responsibility
Skills evaluation ability	Skills	Skills	Development of environmental behavior
Participation	Participation	Active involvement	

importance of technology in education (Figure 2) (Koehler and Mishra, 2009). TPCK is a structure formed by combining three different knowledge components: Technological knowledge, pedagogical knowledge, and content knowledge, in the view of Mishra and Koehler (2006), TPCK:

> Is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones (p. 1029).

The development of TPCK by teachers is critical to effective teaching with technology (Koehler et al., 2017). This is because TPCK is a beneficial concept for thinking about the integration of technology into teaching and how teachers might then develop this knowledge (Schmidt et al., 2009).

Nowadays, stakeholders of education should think critically about how to integrate STEM education into science teaching with the concept of STEM starting to take place in the current science curriculum. For this reason, the importance

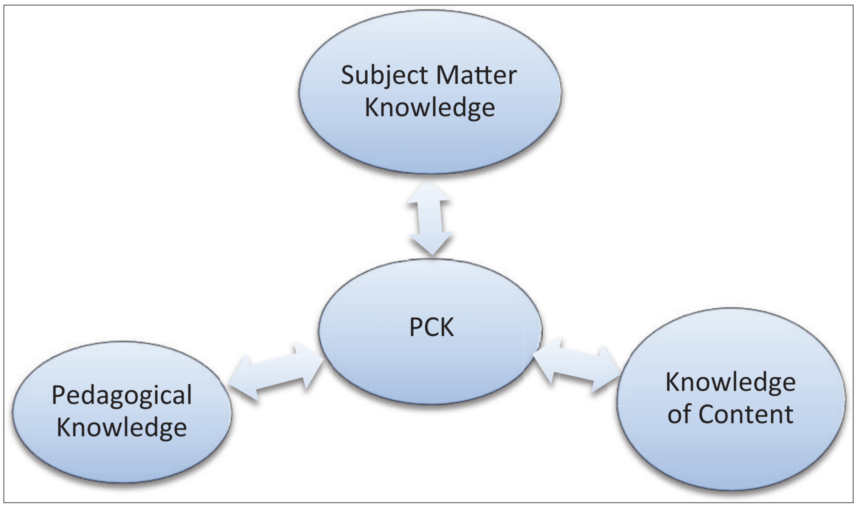

Figure 1: The model of teacher knowledge. In this model, pedagogical content knowledge is presented as a unique knowledge domain (van Dijk and Kattmann, 2007)

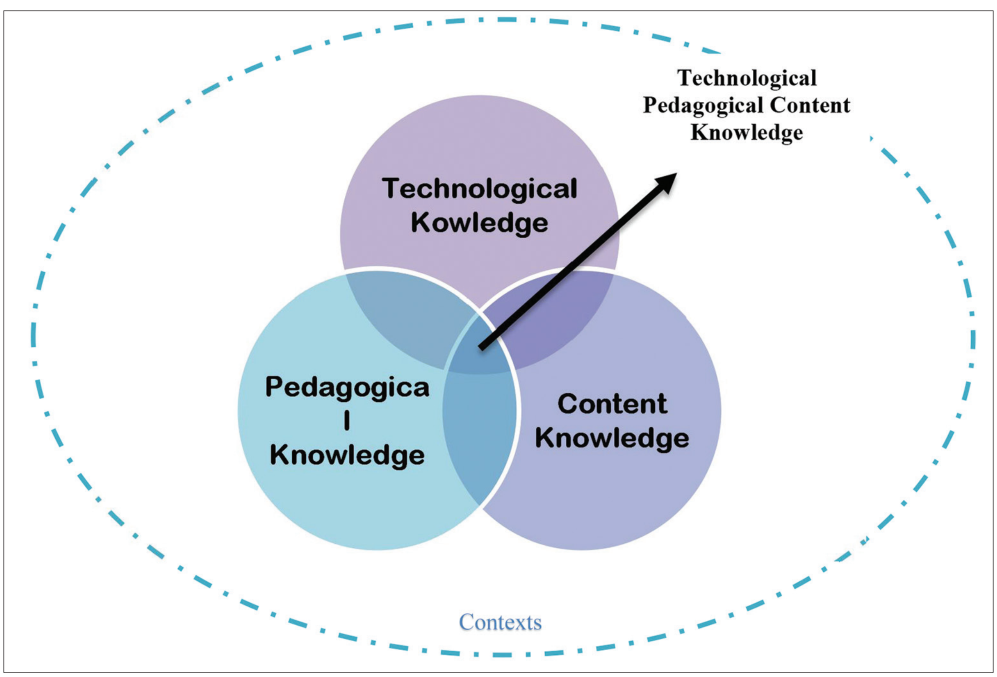

Figure 2: Technological pedagogical content knowledge (Koehler and Mishra, 2009)

of the relationship between STEM and PCK has emerged for fostering teachers' professional development.

WHY DO WE NEED THE INTEGRATION OF THE STEM CONCEPT INTO THE PCK?

Pedagogical knowledge is used to facilitate effective teaching practices in ways that aim to make learning more accessible to students (Hudson et al., 2015). When pedagogy is most successful, teachers and students work together toward the shared purpose of learning (Association of American Universities, 2018).

One of the things to be aware of for the quality of STEM education is teacher education. The quality of the teacher education directly affects the teaching process. Teacher content knowledge is one of the paramount elements for the improvement of teaching and learning (Ball et al., 2008). However, teacher education programs rarely connect content instruction with pedagogy; furthermore, if a teacher candidate is not specializing in a STEM-related field, STEM content preparation in pre-service training tends to be inadequate (York, 2018). Therefore, teachers should be supported to increase their experience in STEM teaching and learning not only in pre-service but also in in-service training. Therefore, governments support educators'/teachers' knowledge and expertise in STEM disciplines through recruitment, preparation, support, and retention strategies (United States Department of Education, 2017).

First, to increase the knowledge and experience of teachers and educators in STEM teaching, STEM concept should be integrated into the PCK. Saxton et al. (2014) offer the concept of "STEM PCK," and they mention that the purpose of STEM PCK is to focus on student thinking about and useful strategies for teaching related to STEM topics. The term "STEM-PCK," an acronym for science, technology, engineering, and mathematic PCK (Figure 3).

A good structure of STEM PCK ensures that teachers have the necessary knowledge to identify and measure their students' development of concepts related to STEM, inquiry-based processes, and real-world connections to alter intentionally their instruction in productive ways (Allen et al., 2016).

RESEARCH QUESTION

In this study, the main goal of the research is to determine teachers' experiences and qualifications as E+STEM literate individuals for the development of environmental literacy in accordance with expert opinions.

> Q1: What should be done to promote the development of E+STEM literate individuals?

RESEARCH METHODS AND DESIGN

In this study, a mixed method research design was used to reveal expert opinions about the concept of E+STEM literacy. This type of research design combines qualitative and quantitative data (Creswell, 2014), which provides more comprehensive coverage of the research topic (Conti, 2012). The exploratory sequential design, a type of mixed method research, was used. Through the exploratory sequential design, the results of qualitative research are the basis for subsequent quantitative research (Creswell et al., 2011).

Based on expert opinions, the Delphi technique was utilized to determine the concept of environmental literacy and to develop the competencies of the environment literate individual. The Delphi

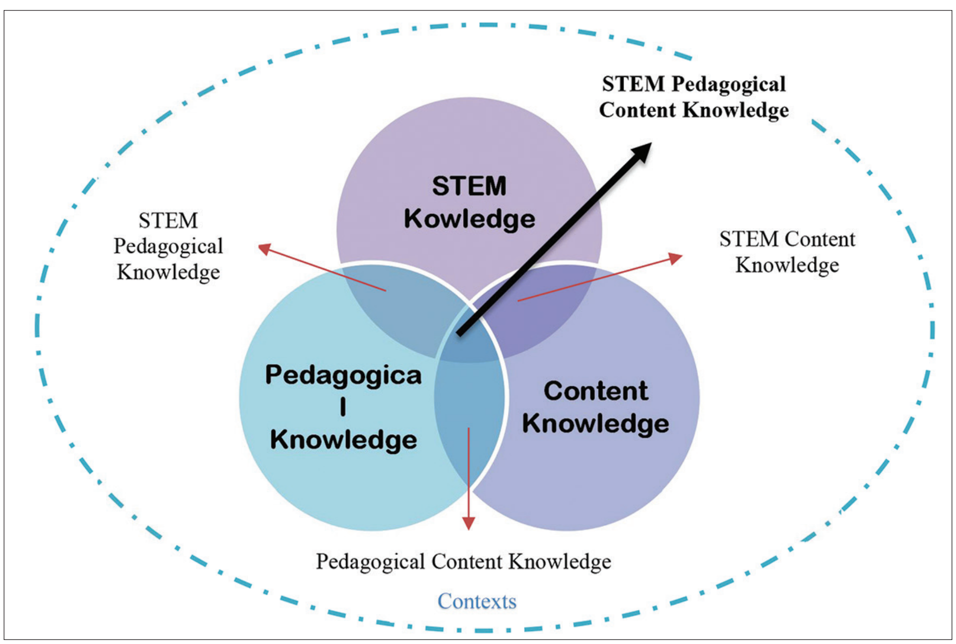

Figure 3: STEM Pedagogical Content Knowledge (Adopted from: Koehler and Mishra, 2009)

technique is used for the collection of views on a specific topic (Villiers et al., 2005). It is a research technique used to obtain a common result using expert opinions to solve a complex problem (Aydin, 1999). This technique usually involves consecutive questionnaires directed to experts (Gencturk and Akbas, 2013) and allows them to explain their opinions freely without being influenced by the views of others (Ashmore et al., 2016). In the Delphi technique, qualitative, quantitative, or mixed method research can be utilized (Skulmoski et al., 2007). Therefore, the combined use of both the mixed method and the Delphi study techniques helps to uncover, define, and reach consensus on the best practices and specific situations for the research topic (Conti, 2012).

Process of the Delphi Study

The Delphi technique prevents participants' direct discussion with each other, and through interviews or questionnaires, participants can question the situation repeatedly (Dalkey and Halmer, 1963). It is used as a means of providing consensus among experts in situations where there are differences of opinion (Şahin, 2001). In this study, the Delphi study was carried out in three steps as seen in Figure 4. Each round contained the data collection tool, the collection of data, and the analysis of the collected data.

In this study, the Delphi study was performed in three

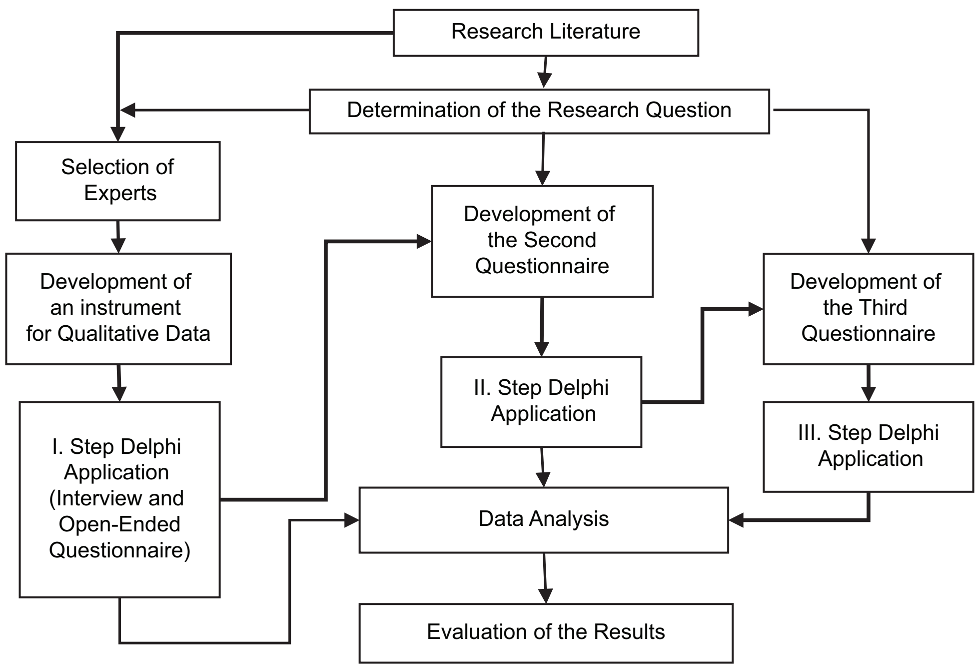

Figure 4: Process of the Delphi study

Table 2: How teachers should develop their experiences and qualifications as E+STEM literate individuals

Item	Round	$\bar{x}$	SD	Med	DBQ	Responses (%) 5-7	4	1-3	Cons	Cons. Dif.
Teachers should have content knowledge about environmental issues	2.R.	6.56	0.63	7.00	1.00	100	-	-	Yes	0.0
	3.R.	6.77	0.50	7.00	0.00	100	-	-	Yes	
Teachers should constantly update their knowledge about environmental issues	2.R.	6.63	0.66	7.00	1.00	97.6	2.4	-	Yes	2.4
	3.R.	6.77	0.50	7.00	0.00	100	-	-	Yes	
Teachers should follow the development of environmental technologies	2.R.	6.34	0.88	7.00	1.00	97.6	-	2.4	Yes	2.4
	3.R.	6.45	0.77	7.00	1.00	100	-	-	Yes	
Teachers should apply technology related to the environment (nanotechnology, environmental technologies, etc.)	2.R.	6.12	1.15	7.00	1.50	91.8	4.9	4.9	Yes	-1.8
	3.R.	6.13	1.01	6.00	1.25	90.0	10.0	-	Yes	
Teachers should have pedagogical competencies to teach about environmental issues	2.R.	6.54	0.75	7.00	1.00	97.6	2.4	-	Yes	-0.6
	3.R.	6.68	0.70	7.00	0.00	96.8	3.2	-	Yes	
Teachers should consistently develop their competencies for teaching environmental topics	2.R.	6.61	0.63	7.00	1.00	100	-	-	Yes	0.0
	3.R.	6.71	0.59	7.00	0.00	100	-	-	Yes	

$\bar{x}$: Mean, SD: Standard deviation, Med: Median, DBQ: Difference between quarters, Cons: Consensus, Cons. Dif.: Consensus difference between the second and third round analysis, responses: 5–7: Weakly to strongly agree, 4: Neutral, 1–3 strongly to weakly disagree. E+STEM: Environmental science, technology, engineering, and mathematics consecutive steps. First, the qualitative data were collected. After the analyses of the data, the quantitative form was developed for the second step of the Delphi study. After the analyses of the data collected in the second step, the final quantitative form (for the third step) was prepared.

The development of questionnaire forms and data analysis methods are structured according to the three steps (Schulte, 2017). However, in the Delphi method, qualitative data from the first round are obtained, and then this data provide the basis for the quantitative data in both the second and third rounds (Cartwright, 2014).

Sample

It is performed in three consecutive steps in Delphi study. The sample consisted of 45 experts who volunteered to participate in the study. These 45 experts have PhD degrees related to environmental education and were selected using purposive sample method. These experts work as a scientist/an educator/a teacher in the European Union (40), the United States, and Africa (5). The numbers of the participants in the first, second, and third Delphi study steps were 20, 44, and 31, respectively.

Data Analysis

To understand whether consensus had been reached statistically, the mean, standard deviation, median, difference between quarters, responses %, consensus (cons), and consensus difference (cons. dif.) were recorded. These results are presented in the Results' Table 2.

RESULTS

The results obtained at the end of the first round were used in both the 2nd and 3rd rounds. Each question represents each theme and each item represents each code.

In the interviews and questionnaires, some questions were asked to determine the experts' views on how teachers develop their experiences and qualifications as E+STEM literate individuals. The majority of experts believed that "Teachers should have content knowledge about environmental issues and have pedagogical competencies to teach about the environmental issue" (Table 3).

As seen in Table 3, at the end of the Delphi study, there was a consensus on six items about how teachers should develop their experiences and qualifications as E+STEM literate individuals. When second and the third Delphi results were compared, the percentage of "teachers should constantly update their knowledge about environmental issues and follow the development of environmental technologies" increased, however, the percentage of "teachers should apply technology related to the environment" decreased.

DISCUSSION

Teaching skills and a teacher's disposition are important for the development of qualified environmentally literate individuals (Kaya and Elster, 2018). Therefore, it is necessary to focus on teacher training and professional development (National Environmental Education Advisory Council, 2015). It was concluded that there was a consensus about "having and updating content knowledge about environmental issues," "following the development of environmental technologies, and applying them in class." There was additional agreement about "having and developing pedagogical competencies for the development of teachers" experiences and qualifications as E+STEM literate individuals. Experts believe in the importance of teachers' having knowledge about the pedagogical knowledge as well as environmental knowledge and updating them. In particular, science teachers should update their PCK and their experiences in light of the increasing importance of

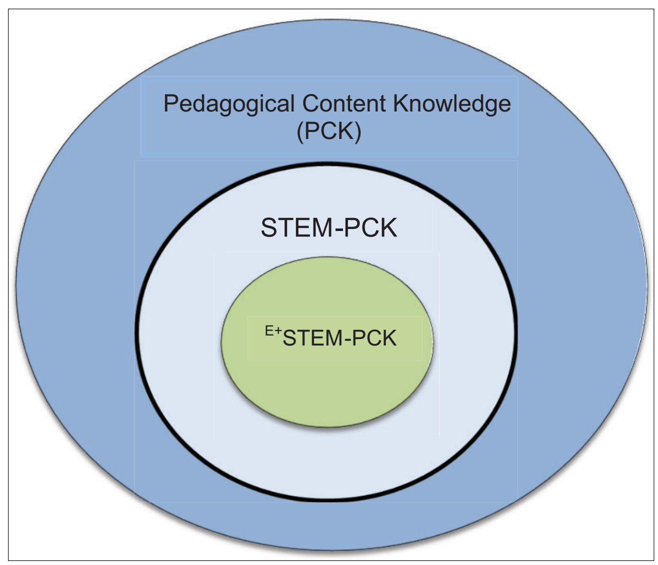

Figure 5: Integration of environmental into the science, technology, engineering, and mathematics pedagogical content knowledge

Table 3: Views on how teachers develop their experiences and qualifications as E+STEM literate individuals (Qual.)

Themaa	Code	n
Responsible of teacher as environmental literate individuals	To have content knowledge about environmental issues	3
	To have pedagogical competencies to teach about the environmental issues.	3
	To update their knowledge about environmental issues	2
	To apply the technology related to environment (nanotechnology and environmental technologies etc.)	1
	To follow the development of the environmental technologies	1
	To develop their competencies for teaching environmental topics.	1

E+STEM: Environmental science, technology, engineering, and mathematics

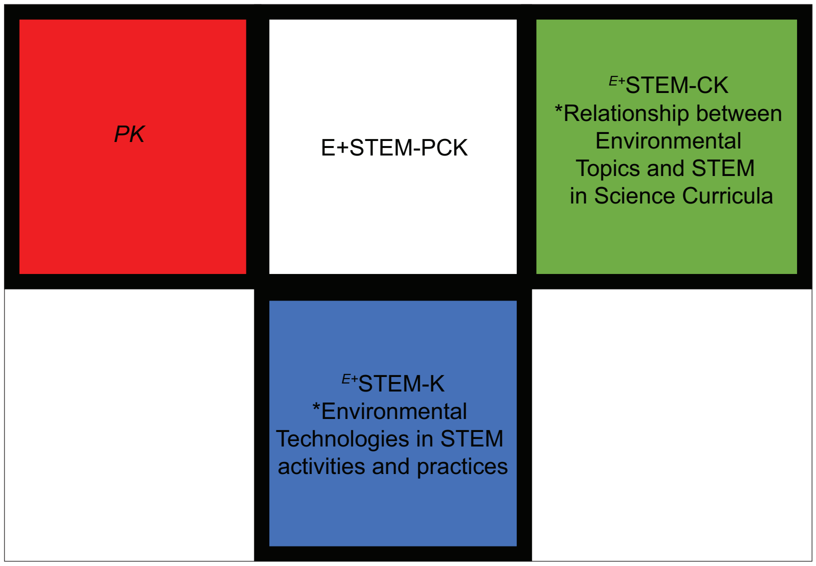

Figure 6: Components of environmental science, technology, engineering, and mathematics pedagogical content knowledge for science teaching. Note: When colors of blue, green, and yellow are mixed, the white color occurs

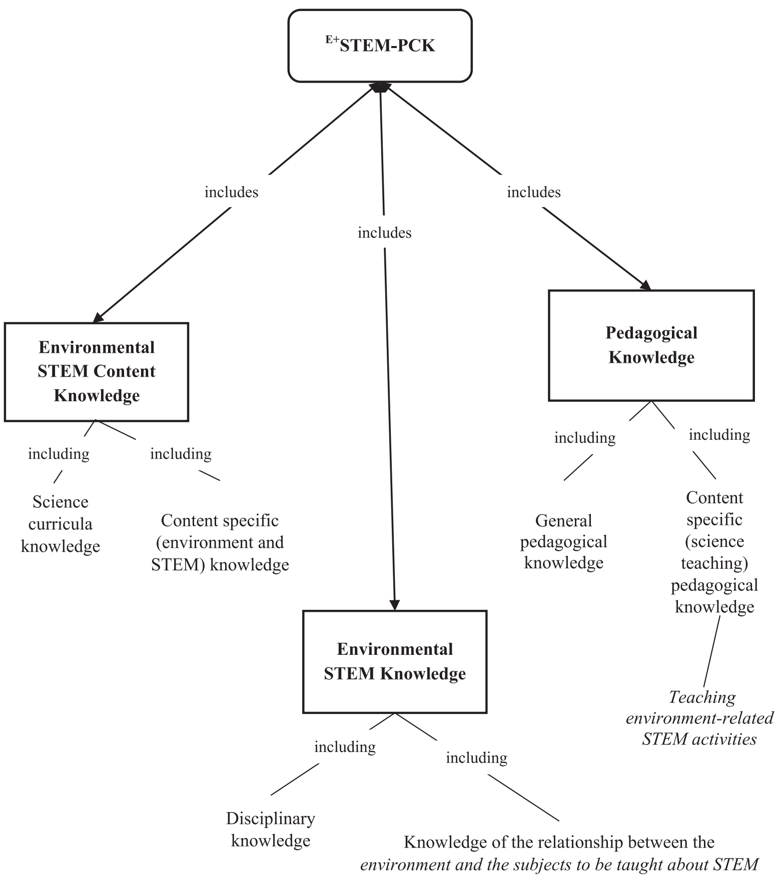

Figure 7: Environmental science, technology, engineering, and mathematics pedagogical content knowledge and its components

STEM education. A robust STEM PCK ensures that teachers have the necessary knowledge to identify and measure their students' development of concepts related to STEM (Allen et al., 2016). With STEM-PCK, teachers have knowledge of both the environment and STEM and gain experience in how to integrate these two concepts into each other. By this means, science education might meet expectations of present and future generations.

On the other hand, it is thought that the concept of STEM education will be more specifically addressed for more qualified and specific STEM education. The framework of 'Science' in STEM is very broad for this reason, it may be predicted that new nomenclature related to STEM will increase to develop the applications that reveal the specific relation of the different branches of science. Else, adding different and new dimensions (such as in art) to STEM education, it is possible to try to reveal the importance of new dimension added in STEM education (such as Science-Technology-Engineering-Art-Mathematics [STEAM]), as well as its framework widened (STEAM education).

For instance, between 2011 and 2015, The Korean government decided to include STEAM education in education policy (The Korean Ministry of Education, Science and Technology, 2011, as cited Hong, 2017). Another example, the NSF has an integrated the concept of computing into the STEM education (STEM+C) (NSF, 2018). The other example is the attempt to integrate the concept of the environment into both the framework of the STEM-PCK in this study (Figure 5).

CONCLUSION AND RECOMMENDATIONS

The results show that teachers' professional development is a key factor that promotes the development of E+STEM literate individuals. Thus, qualified E+STEM literate individuals require qualified E+STEM literate teachers. Additional environmental education should become part of the academic teacher training programs in universities. In particular, the concept of "environment" should be integrated into the framework of STEM-PCK for teacher's professional development (Figure 6). The determination of E+STEM PCK (E+STEM-PCK) includes three different knowledge components: E+STEM-Content knowledge (knowledge on STEM and Environment), pedagogical knowledge (knowledge on how to teach environment-related STEM activities), and E+STEM-Knowledge (disciplinary knowledge required for the integration of STEM as environmentally-friendly, in additional knowledge of the relationship between the environment and the subjects to be taught about STEM).

In this Figure 6, teachers' knowledge, which is equally important, has three core components. Shulman (1986) described the combination knowledge of pedagogy and content as PCK. In this paper, it is described the combination knowledge of pedagogy, content (not only fields of STEM but also environment), and associating disciplines with each other (Figure 7).

By this means, a new educational and environmental concept, E+STEM-PCK, would be incorporated into teacher education. Then, future research might determine the scope of E+STEM-PCK in the light of the framework of PCK and STEM-PCK and how it can be taught to teachers, thereby increasing the quality of STEM education. In addition, the concept of "environment" should be integrated into the framework of STEM education allowing evolution to environment conscious STEM education (E+STEM) in science classes and curricula.

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