TECHNOLOGICAL, PEDAGOGICAL, AND SCIENCE KNOWLEDGE (TPASK) OF PUBLIC SCHOOL SCIENCE TEACHERS

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ABSTRACT*: The study aimed to evaluate the Technological Pedagogical Science Knowledge (TPASK) of science teachers in the Division of El Salvador, Department of Education located in Misamis Oriental, Philippines. The evaluation results will be used for the development of a training design intended for science teachers. A modified and validated 76 item survey instrument was used to gather the data. A total of 73 in-service Grade 3 to Grade 12 science teachers from 23 schools participated in the study. Descriptive statistics was used to described the Technological Pedagogical Science Knowledge (TPASK) of science teachers. Results indicated that there is perceived low competence in employing simulations and other technological applications in teaching science concepts. The science teachers also indicated a moderate to high competence in science knowledge and pedagogy that may have resulted from varied teaching experience, educational background and training attended. Recommendations include in the prioritization for capability building the areas that the science teachers perceived to be less capable of implementing.*

Key Words: professional development, science teaching, Technological Pedagogical Content Knowledge, in-service training

1. INTRODUCTION

Technological Pedagogical Content Knowledge (TPCK) has been implemented into the field of academic research as a theoretical framework for the understanding of teacher skills needed for successful integration of technology [1]. TPACK depicts the dynamic relationship between knowledge of material, pedagogical knowledge and technical awareness to direct teachers in strategic thinking about when, where and how to direct learning through technology [2]. The TPCK framework acronym has been renamed TPACK in order to make it easier to remember and to create a more cohesive whole for the three forms of knowledge: technology, pedagogy and content for science teacher education. Both pre-service and in-service science teachers are trained to develop and enhance teaching skills based on the application of TPACK through a wide variety of capacity building, i.e., courses, training and seminars, and through teacher education. [3, 4]. Clearly, the implementation of the TPACK-based science teacher education system is essential in preparing both pre-service and in-service science teachers to learn high-quality teaching skills by incorporating technology into their science teaching practice [5]. Further, integration of technology is rooted primarily in curriculum design and design-related learning processes, and secondly in the informed use of educational technologies [6]. However, due to the overwhelming use of mobile technology to promote inquiry-based teaching and learning in science, teachers' knowledge of science concept, pedagogy and technology and their engagement is important in order to incorporate mobile technology successfully into the science classroom [7]. Hence, the step in this effort to design and establish a coherent TPACK structure for the training of science teachers, and to make the links between science content, pedagogy, and technology clear in a meaningful and practical for secondary education settings [8]. This is important as teachers recognize that effective science teaching can improve the students' poor background in science [9]. Most importantly, teachers recognize that they can assist students' difficulty in science by applying a variety of teaching strategies suitable to the students' needs [10].

Thus, this research aimed to evaluate the Technological Pedagogical Science Knowledge (TPASK) of Teachers in the Division of El Salvador as basis for a training design for science teachers. It is hoped that a new paradigm for professional development based on integrated structure established by the Technological Pedagogical Content Knowledge (TPACK) framework will be in place. As the country and the rest of the world is trying to reduce the negative effects of the pandemic to the delivery of quality education, shift to flexible learning modality, including the use of online resources has become the new normal. With the continuous emergence of new and emerging technologies available for use in education, it is important to assess later the extent to which the use of digital technology contributes to learning and teaching [11].

2.METHODOLOGY

2.1 Research Design

This study used a descriptive survey approach to obtain information of the in-service science teachers' Technological Pedagogical Science Knowledge.

2.2The Instruments

The TPASK questionnaire was adapted and modified for the in-service science teachers within the context of the El Salvador City division from the standardized TPASK tool. The original survey instrument contains 85 items but was reduced to 76 items using Cronbach's Alpha. Reliability coefficient was then established at 0.9846 using the PSPP software. The modified instrument used to measure the TPASK level is grouped into 4 components namely: (a) Technological Pedagogical Knowledge (TPK) which includes the technological knowledge, application of technology, technological and pedagogy; (b) Technological Science Knowledge; (c) Pedagogical Science Knowledge; and (d) Technological Pedagogical Science Knowledge. The instrument contains Likert-type scale items with a five-point scale (1= *strongly disagree*, 2 = *disagree*, *3= neither agree or disagree*, 4= *agree*, 5= *strongly agree*) to assess participants' levels of TPASK.

2.3 The Respondents

In-service science teachers from 23 schools categorized as elementary, secondary and integrated schools were asked to participate in the study. Informed consent was obtained and assurance of confidentiality of their responses were provided. The participants were aware that the results will be reported as training needs assessment for the whole division and that their full participation will help in making sure that relevant training can be implemented based on their needs for the teaching in the new normal.

2.4 Data-Gathering Procedure

The survey questionnaires were distributed to identified schools and participants as Google forms whose link is indicated in an email that communicated the intent and scope of the survey after consent to conduct the study from the Division Office was obtained. A division memorandum was issued to encourage the science teachers to participate in the survey.

Then the collected responses from the google forms were processed using PSPP program for statistical analysis. The data was gathered for about a month from November 2020-December 2020. Participants had the option, to voluntarily complete an online version of the questionnaire using Google forms for one month from the moment survey link was received.

RESULTS AND DISCUSSIONS

Profile of the Respondents

The majority of the respondents of the study are relatively young (23- 44 years of age) and some are in their prime. In terms of highest educational qualification, majority are bachelor's degree holder and very few were able to obtain a graduate degree. As to the grade level taught, majority are in the elementary level. Majority of the teacher respondents were already teaching for more than 4 years. For TPASK, only items of interest are reflected in the tables.

Table 1 shows the results of the teachers' self-assessment of their technological pedagogical knowledge (TPK). TPK describes relationships and interactions between technological tools and specific pedagogical practices. The over-all mean's interpretation indicated that this construct can be a second priority for capability training. However, the results for the sub-items indicated that majority of the science teachers considered the use and incorporation of simulation, applications, software and digital media to science teaching to be among their least capable of implementing in their classrooms. This would also mean that these TPK items may be considered as the priority areas or focus for capability training. Simulation is considered to be a tool in teaching science and its effectiveness is only limited in the way it is used in the classroom [12]. Its benefits to students are numerous as identified by studies [13] that asserted simulation can make abstract science phenomena more accessible and visible to students.

Teachers evaluating their instructional performance on ICT usage was one of the key measures for fostering TPACK development [14]). This suggests that teachers used their professional reasoning skills to guide their ICT use in the classroom as a strategy to improve their TPACK [15]. The way teachers use ICT in the classroom is determined by their pedagogical thinking [16]. In order to use ICT to enhance pedagogical techniques, teachers must use their TPK in their professional reasoning to make decisions about which pedagogical techniques to deploy in their classrooms [17]. Teachers' practical experience (and thus their professional reasoning) is based on both formal and informal knowledge acquired through education and training and experiences in specific circumstances [18]. TPK, can then be defined as the sum of all the knowledge and insights that underpin teachers' use of pedagogical approaches in connection with ICT in their particular classroom practices [19]. As a result, rather than the ICT tools themselves, it is the teachers' pedagogical practices for teaching and learning that promote their ICT use [20].

Table 1. Technological Pedagogical Knowledge

Domains of TPASK	**Mean**	**SD**	**Level of Capability**	**Level of Priority Development**
A. Technological Pedagogical Knowledge	2.89	1.07	Moderate	Moderate
6. I can use dynamic drawing software (e.g., ChemSketch, Chem Doodle, etc).	2.03	1.03	**Low**	**High**
7. I construct multimedia objects embedding pictures, sound and animations.	2.51	1.18	**Low**	**High**
9. I can operate the effective use of simulation software to model specific content.	2.58	1.06	**Low**	**High**
10. I can operate the effective use of conceptual mapping software to model specific content.	2.4	1.05	**Low**	**High**
11. I can operate the effective use of Microcomputer based laboratory settings to support experimentation in specific subject content.	2.23	1.02	**Low**	**High**
13. I can use simulations of specific scientific knowledge (macroscopic and microscopic)	2.41	1.1	**Low**	**High**
14. I can use virtual experimentation.	2.49	1.15	**Low**	**High**
15. I can use experimentation using microcomputer-based laboratory.	2.15	0.93	**Low**	**High**
20. I can use modelling and simulation methods of specific content in science (e.g., concepts, processes, principles)	2.58	1.1	**Low**	**High**
22. I have knowledge and skills to identify pedagogical properties of specific software	2.45	0.95	**Low**	**High**
23. I can analyze and evaluate scientific content in digital media.	2.54	1.08	**Low**	**High**

Although, sometimes difficult to really measure,content knowledge is one of numerous forms of knowledge necessary for efficient science teaching [21]. Teachers with more content expertise are more likely to teach in ways that assist students develop knowledge, such as by asking appropriate questions, suggesting alternate interpretations, and suggesting subsequent inquiry [22]. Understanding of how technology can develop new representations for certain contents and enhance the practices and knowledge of a given subject is known as technological content knowledge (TCK) [23]. The authors asserted that teachers recognize that by incorporating a specific technology into their teaching and learning, they may alter how students practice and comprehend topics in a certain curriculum area. The basis of TPCK is the teachers' creativity and flexibility in designing classes and experimenting with technology to fit students' specific learning requirements [24]. Indeed, designing is an essential task for teachers, because the capacity to use ICT in a meaningful way necessitates teachers' ability to synthesize relevant components of TPCK [25].

Table 2 presents the Technological Science Knowledge (TSK) survey results. The over-all mean reflected that TSK is not a priority for training. However, items to be considered as point of interest for training includes history and philosophy of science as well as on its structure, facts, theories and practices. In addition, science teachers indicated that need to learn more on the different approaches in solving science problems. If this particular skill is enhanced, this is a higher possibility for the science teachers to foster creativity, innovation and problem-solving skills among students.

Table 2. Technological Science Knowledge

	Mean	**SD**	**Level of Capability**	**Level of Priority Development**
B. Technological Science Knowledge	3.42	0.93	High	Low
30. I have sufficient knowledge about sciences.	3.56	0.86	High	Low
31. I can provide sufficient support to learners to solve a science problem.	3.5	1	High	Low
32. I have various strategies of developing my understanding about sciences.	3.63	0.95	High	Moderate
33. I know about a lot of different approaches of solving science problems.	3.26	0.92	Moderate	Moderate
34. I know the structure of science.	3.32	0.92	Moderate	Moderate
35. I know the facts, theories and practices.	3.37	0.93	Moderate	Moderate
36. I know the history and philosophy of science.	3.32	0.9	Moderate	Moderate

Content knowledge is one of numerous forms of knowledge necessary for efficient science teaching, despite its difficulty in measurement [26]. Teachers with more content expertise are more likely to teach in ways that assist students develop knowledge [27]. Understanding of how technology can develop new representations for certain contents and enhance the practices and knowledge of a subject is known as technological content knowledge (TCK) [28]. The authors claimed that teachers recognize that by incorporating a specific technology into their teaching and learning, they may alter how students practice and comprehend topics in a certain curriculum area. The basis of TPCK is teachers' creativity and flexibility in designing classes and experimenting with technology to fit students' specific learning requirements [29]. As a result, designing is an essential task for teachers, because the capacity to use ICT in a meaningful way necessitates teachers' ability to synthesize relevant components of TPCK for a specific set of students, with a particular focus on certain content knowledge [30].

Table 3 presents the pedagogical science knowledge of the respondents. The over-all mean indicated that these items collectively are not priorities for training. Nevertheless, the areas that can be considered for capability training are how to organize scientific knowledge (facts, theories, practices) and determine multiple representations of scientific knowledge (pictorial, graphical, vector, mathematical).

The challenge for teacher education is to train teachers to teach from an integrated knowledge structure of teaching their subject matter—the intersection of content knowledge with understanding of pedagogy, or pedagogical content knowledge (PCK) [31]. The foundation for providing clear explanations and identifying relevant and correct representations of concepts is a deep and cohesive grasp of science knowledge [32]. This pedagogical approach is at the center of the PCK discussion, and it allows teachers to pass on their knowledge in a variety of ways to their students [33]. Teachers must be able to organize an effective science curriculum that incorporates many representations and models of the topics that focus on the fundamental topics [34]. Pedagogical content knowledge varies by content area, as it combines both content and pedagogy with the purpose of improving teaching techniques [35].

Table 3. Pedagogical Science Knowledge

	Mean	SD	Level of Capability	Level of Priority Development
C. Pedagogical Science Knowledge	3.49	0.85	High	Low
44. I know how to organize scientific knowledge (facts, theories, practices).	3.36	0.94	**Moderate**	**Moderate**
45. I can easily determine multiple representations of scientific knowledge (pictorial, graphical, vector, mathematical).	3.13	0.89	**Moderate**	**Moderate**

While many fields of knowledge contribute to effective teaching, research on the qualities of effective science teachers emphasizes the significance of a comprehensive understanding of science subject in order to enable changes in teaching practice [36]. Also, a variety of researchers have looked into trainee teachers' PCK in science teachers. For instance, consider the role of children's science conceptions in the development of trainee teachers' pedagogical approaches for teaching sound, light, and electricity [37]. They created an intervention that combined trainees' examination of their own concepts and practical with children's understandings [38]. Researchers added that by comparing pre- and post-intervention concept maps, trainees' understanding enhanced, and their understanding of children's misconceptions improved their instruction toward reformation rather than transmission of knowledge.

Table 4 shows the Technological Pedagogical Science Knowledge survey results. This is a priority for training as indicated in the sub-items although the over-all mean only amounts to moderate level of priority for development. It is evident from the results that there is a high need for modeling and mentoring to promote the use of technology in science instruction. If there would be more models for prospective science teachers to emulate then perhaps, we could have an excellent community of practice focused on quality science education.

Table 4. Technological Pedagogical Science knowledge

	Mean	SD	Level of Capability	Level of Priority Development
D. Technological Pedagogical Science Knowledge	2.85	0.96	Moderate	Moderate
69. My science education professors appropriately model combining science, technologies and teaching approaches in their teaching.	2.50	0.98	**Low**	**High**
72. My professors outside of education appropriately model combining content, technologies and teaching approaches in their teaching.	2.46	0.96	**Low**	**High**
73. My cooperating teachers appropriately model combining science, technologies and teaching approaches in their teaching.	2.56	0.95	**Low**	**High**
76. In general, approximately what percentage of the cooperating teacher/s have provided an effective model of combining science, technologies and teaching approaches in their teaching?	2.59	1.01	**Low**	**High**

The researcher conducted an interview with science teachers from elementary to senior high school to validate the findings of the technological pedagogical science knowledge based on the episode where science education instructor or professor, cooperating teachers, and the in-service science teachers effectively modelled or demonstrate combining science, technologies, and teaching approaches in a classroom lesson. In order to address this problem statement, interviews were conducted to select science teachers. The researcher used an open-ended question with the select science teachers from elementary to senior high school to validate the findings of the technological pedagogical science knowledge based on the challenges that the teacher encountered in the attempts to incorporate technology and pedagogy in the classroom. The findings were grouped thematically. The themes consist of eight items: (a) problems in internet connection; (b) problems in technology integration; (c) limited knowledge of offline software; (d) problems in selecting appropriate ICT materials; (e) problems in technology integration lack of technical support in classroom setting; (f) depth of curriculum assistance; (g) less administrative support.

In terms of the teachers' challenges to incorporate technology and pedagogy to in classroom instructions, the findings were largely consistent with the quantitative results. Teachers reported that integrating technology was limited due to network availability in their schools. Based on the interview, the study found that teachers lack of skills necessary to manipulate certain software application and limited knowledge on ICT and offline laboratory application. One of the teachers described his experience in the following words,

"*The different challenges we encountered were limited ICT equipment, lack of proper skills training for the teachers, inadequate internet connection, unavailability of latest ICT equipment, lack of expert technical staff, and poor administrative support*"

Also, the researcher found that there was limited access of offline learning resources. The teacher experienced inappropriateness of learning resources available in the computers versus the learning competency that the teacher wanted to discuss. The lack of relevant and appropriate software is a major impediment to the expansion of computer use in most schools. It is then resulted to the difficulty of teachers in choosing the appropriate ICT instructional materials for lessons found online. The majority of teachers acknowledged that they often face technical support issues, a lack of time in school to fully utilize ICT equipment, and a lack of awareness and expertise about how to fully utilize ICT. Without a doubt, this problem may lead to a lack about understanding of how to incorporate ICT into teaching and learning.

TPACK is a form of thinking critically while planning, organizing, critiquing, and abstracting for individual subject, individual student needs, and individual classroom scenarios, while also addressing the diversity of twenty-first-century innovations that have the capacity to encourage student learning [39]. To help learners build knowledge and understanding of numerous science subjects, science teachers must have enough knowledge in science [40]. Also, a teacher with extensive pedagogical content knowledge uses effective teaching practices, generates well-designed lesson plans, uses effective classroom management approaches, and establishes a knowledge of student learning [41]. Teachers should build an encompassing concept of their subject matter in terms of technology and what it signifies to teach with emerging technologies technology to become an integral component or instrument for learning in science [42]. In addition, science teacher preparation should focus on guiding the growth of their knowledge and thinking in a way that addresses the formation of an overarching vision of educating using technology. This is because technology knowledge has a scientific foundation. Thus, using demonstrations and labs/hands-on activities to teach science with technology is consistent with main pedagogical techniques. These four knowledge bases (understanding of, science, students, pedagogy, and technology collaborate "in knowing where in the curriculum] to utilize technology, what technology to apply, and how to teach with it") [43]. Nevertheless, technological knowledge entails more than just understanding about technology; it also involves a thorough understanding of how to apply technology to classroom education, interaction, problem-solving, and decision-making [44].

CONCLUSIONS AND RECOMMENDATIONS

The use of the TPASK framework is helpful to determine the priority areas for capability training. By providing what is the most urgent needs in line of what is existing and what is the demand of the times, limited resources can be put to better use. Most importantly, this capability training for online teaching skills is relevant to current flexible learning trend.

5. REFERENCES

[1] Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017-1054.Retrieved from https://www.learntechlib.org/p/99246/

[2] Thompson, A. D., & Mishra, P. (2007). Editors' remarks: Breaking news: TPCK becomes TPACK!. *Journal of Computing in Teacher Education*, 24(2), 38-64. Retrieved from https://doi.org/10.1080/10402454.2007.10784583

[3] Srisawasdi, N., & Panjaburee, P. (2014). Technology-enhanced learning in science, technology, and mathematics education: results on supporting student learning. *Procedia – Social and Behavior Sciences*, Vol. 116, pp.946–950.

[4] Qasem, A. A., & Viswanathappa, G. (2016). Teacher perceptions towards ICT integration: Professional development through blended learning. *Journal of Information Technology Education: Research*, 15, 561-575. Retrieved from https://doi.org/10.28945/3562

[5] Srisawasdi, N., Pondee, P., & Bunterm, T. (2018). Preparing pre-service teachers to integrate mobile technology into science laboratory learning: an evaluation of technology-integrated pedagogy module. *International Journal of Mobile Learning and Organisation*, 12(1), 1-17.

[6] Harris, J. B., & Hofer, M. J. (2017). "TPACK stories": Schools and school districts repurposing a theoretical construct for technology-related professional development. *Journal of Research on Technology in Education*, 49(1-2), 1-15. Retrieved from https://doi.org/10.1080/15391523.2017.1295408

[7] Srisawasdi, N., Pondee, P., & Bunterm, T. (2018). Preparing pre-service teachers to integrate mobile technology into science laboratory learning: an evaluation of technology-integrated pedagogy module. *International Journal of Mobile Learning and Organisation*, 12(1), 1-17.

[8] Jimoyiannis, A. (2010). Designing and Implementing an Integrated Technological Pedagogical Science Knowledge Framework for Science Teachers Professional Development. *Computers & Education*, 55(3), 1259-1269. Retrieved from https://doi.org/10.1016/j.compedu.2010.05.022

[9] A. M. P. Walag, M. T. M. Fajardo, F. M. Guimary, and P. G. Bacarrisas, "Science Teachers" Self-Efficacy in Teaching Different K to 12 Science Subjects: The Case of Cagayan de Oro City, Philippines," *Science International*, vol. 32, no. 5, pp. 587–592, 2020.

[10] M. A. A. C. Bug-os, M. M. P. Walag, and M. T. M. Fajardo, "Science Teacher's Personal and Subject-Specific Self-Efficacy in Teaching Science: The Case of El Salvador City, Philippines", *Science International*, vol. 33, no.3, pp 179-186, 2021

[11] Iriti, J., Bickel, W., Schunn, C., & Stein, M. K. (2016). Maximizing research and development resources: identifying and testing "load-bearing conditions" for educational technology innovations. *Educational Technology Research and Development*, 64(2), 245-262. Retrieved from https://doi.org/10.1007/s11423-015-9409-2

[12] Widiyatmoko, A. (2018). The Effectiveness of Simulation in Science Learning on Conceptual Understanding: A Literature Review. *Journal of International Development and Cooperation*, *24*(1), 35-43).

[13] Muller, D. A., Bewes, J., Sharma, M. D., & Reimann, P. (2008) . Saying the wrong thing: Improving learning with multimedia by including misconceptions. *Journal of Computer Assisted Learning*, *24*(2), 144-155

[14] Yeh, Y. F., Hsu, Y. S., Wu, H. K., & Chien, S. P. (2017). Exploring the structure of TPACK with video-embedded and discipline-focused assessments. *Computers & Education*, *104*, 49-64.

[15] Heitink, M., Voogt, J., Fisser, P., Verplanken, L., & van Braak, J. (2017). Eliciting teachers' technological pedagogical knowledge. *Australasian Journal of Educational Technology*, 33(3). Retrieved from https://ajet.org.au/index.php

[16] Hakkarainen, K., Muukonen, H., Lipponen, L., Ilomäki, L., Rahikainen, M., & Lehtinen, E. (2001). Teachers' information and communication technology (ICT) skills and practices of using ICT. *Journal of Technology and Teacher Education*, *9*(2), 181-197.

[17] Yeh, Y. F., Hsu, Y. S., Wu, H. K., & Chien, S. P. (2017). Exploring the structure of TPACK with video-embedded and discipline-focused assessments. *Computers & Education*, *104*, 49-64.

[18] Koh, J. H. L., Chai, C. S., & Tay, L. Y. (2014). TPACK-in-Action: Unpacking the contextual influences of teachers' construction of technological pedagogical content knowledge (TPACK). *Computers & Education*, 78, 20-29. Retrieved from http://dx.doi.org/10.1016/j.compedu.2014.04.022

[19] Yeh, Y. F., Hsu, Y. S., Wu, H. K., & Chien, S. P. (2017). Exploring the structure of TPACK with video-embedded and discipline-focused assessments. *Computers & Education*, *104*, 49-64.

[20] Tondeur, J., Pareja Roblin, N., van Braak, J., Voogt, J., & Prestridge, S. (2017). Preparing beginning teachers for technology integration in education: Ready for take-off?. Technology, *Pedagogy and Education*, 26(2), 157-177. Retrieved from https://doi.org/10.1080/1475939X.2016.1193556

[21] Van Driel, J. H., Verloop, N., & De Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *35*(6), 673-695.

[22] Windschitl, M. (2009, February). Cultivating 21st century skills in science learners: How systems of teacher preparation and professional development will have to evolve. In *National academies of science workshop on 21st century skills*.

[23] Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017-1054. Retrieved from https://www.learntechlib.org/p/99246/

[24] Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)?. *Contemporary issues in Technology and Teacher Education*, 9(1), 60-70.

[25] Chai, C.S., Koh, J.H.L., & Tsai, C.C. (2011). Exploring the factor structure of the constructs of technological, pedagogical, content knowledge (TPACK). *The Asia-Pacific Education Researcher*, 20 (3), 595–603. Retrieved from https://ir.lib.ntust.edu.tw

[26] Van Driel, J. H., Verloop, N., & De Vos, W. (1998). Developing science teachers' pedagogical content knowledge. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 35(6), 673-695.

[27] Windschitl, M. (2009, February). Cultivating 21st century skills in science learners: How systems of teacher preparation and professional development will have to evolve. In *National academies of science workshop on 21st century skills*.

[28] Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017-1054. Retrieved from https://www.learntechlib.org/p/99246/

[29] Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)?. *Contemporary issues in Technology and Teacher Education*, 9(1), 60-70.

[30] Chai, C.S., Koh, J.H.L., & Tsai, C.C. (2011). Exploring the factor structure of the constructs of technological, pedagogical, content knowledge (TPACK). *The Asia-Pacific Education Researcher*, 20 (3), 595–603. Retrieved from https://ir.lib.ntust.edu.tw

[31] Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4-14. Retrieved from https://doi.org/10.3102/0013189X015002004

[32] McConnell, T. J., Parker, J. M., & Eberhardt, J. (2013). Assessing teachers' science content knowledge: A strategy for assessing depth of understanding. Journal of Science Teacher Education, 24(4), 717-743.

[33] Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4-14. Retrieved from https://doi.org/10.3102/0013189X015002004

[34] McConnell, T. J., Parker, J. M., & Eberhardt, J. (2013). Assessing teachers' science content knowledge: A strategy for assessing depth of understanding. Journal of Science Teacher Education, 24(4), 717-743.

[35] Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. Teachers College Record, 108(6), 1017-1054. Retrieved from https://www.learntechlib.org/p/99246/

[36] Darling-Hammond, L., & Richardson, N. (2009). Research review/teacher learning: What matters. Educational leadership, 66(5), 46-53.

[37] Jones, M. G., Carter, G., & Rua, M. J. (1999). Children's concepts: Tools for transforming science teachers' knowledge. Science Education, 83(5), 545-557.

[38] Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. Studies in science education, 45(2), 169-204.

[39] Niess, M. L. (2014). Guiding preservice teachers in developing TPCK. In *Handbook of technological pedagogical content knowledge (TPCK) for educators* (pp. 233-260). Routledge.

[40] McCrory, R. A. V. E. N. (2008). Science, technology, and teaching: The topic-specific challenges of TPCK in science. Handbook of technological pedagogical content knowledge (TPCK) for educators, 193-206

[41] Mishra, P., & Koehler, M. J. (2008, March). Introducing technological pedagogical content knowledge. In *annual meeting of the American Educational Research Association* (pp. 1-16).

[42] Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. Teaching and teacher education, 21(5), 509-523.

[43] McCrory, R. A. V. E. N. (2008). Science, technology, and teaching: The topic-specific challenges of TPCK in science. Handbook of technological pedagogical content knowledge (TPCK) for educators, 193-206

[44] Mishra, P., & Koehler, M. J. (2008, March). Introducing technological pedagogical content knowledge. In annual meeting of the American Educational Research Association (pp. 1-16).