








A review of research on pedagogical content knowledge in science and mathematics education in the last five years

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Abstract

This study aims to review Pedagogical Content Knowledge (PCK) studies related to science and mathematics education in the ERIC database. In addition, journals published in the Eric database were searched using the same keyword. Thirty-five science and mathematics education studies were analyzed using standards from the related literature. A qualitative thematic review was conducted in this study. All articles were downloaded and read by the researchers. Each researcher examined them together to determine themes. The themes determined were the subjects and topics studied, the profile of the participants, the data collection instruments, the study design, and the consideration of pedagogical content knowledge with its components. The results were reviewed in terms of the competencies of preservice and in-service science and mathematics teachers in pedagogical content knowledge, the analysis of the development of prospective teachers' pedagogical content knowledge, and the components of pedagogical content knowledge. Some implications of these findings were suggested for determining and developing pedagogical content knowledge of prospective and in-service science and mathematics teachers.

Keywords: pedagogical content knowledge, science education, mathematics education

INTRODUCTION

Pedagogical content knowledge (PCK) was introduced and defined by Shulman (1986) as teachers' ways of representing and formulating subject matter knowledge to facilitate student learning. Shulman (1987) also described PCK as *"that special amalgam of content and pedagogy that is uniquely the province of teachers, their special form of professional understanding."*

According to Shulman (1987), content and pedagogical knowledge should be integrated and not seen as competing. The most important difference between a teacher and a scientist is pedagogical content knowledge. For example, a science or mathematics teacher differs from a scientist in how he or she organizes and presents knowledge to students.

PCK for teaching science and mathematics consists of five components based on Grossman's (1990) and Tamir's (1988) studies: (a) orientations to science

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Contribution to the literature

- This study identified gaps in literature such as no studies on biology existed.
- This study combined findings from multiple studies and provided a comprehensive overview of the literature.
- This study provided a critical evaluation of the existing literature

teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for science teaching.

In the last five years, research on PCK has been conducted in the context of science and mathematics education. Several studies on PCK of preservice teachers on science and mathematics topics exist. These studies generally emphasize that most pre-service teachers do not have sufficient pedagogical knowledge to teach science and mathematics effectively (Belayneh, 2021; Tchoshanov et al., 2019; Usak et al., 2020; Yusupova et al., 2020). Some studies conclude that most prospective elementary teachers have various pedagogical misconceptions and often lack the necessary pedagogical knowledge to teach science effectively (Kuznetsova et al., 2021; Ozden, 2008; Usak et al., 2011).

METHOD

This study is a literature review of science and mathematics education in the database ERIC. PCK and science and mathematics education were used as keywords in the ERIC database. After searching for keywords, 86 articles were found by selecting full-text and peer-reviewed articles. Finally, 35 articles were found after selection in 2018. These articles were reviewed in detail one by one. In this study, a qualitative thematic review was conducted. All articles were downloaded and read by the researchers. Each researcher examined them together to determine the themes. The themes were determined as follows: i) subjects and topics studied ii) profile of participants, iii) data collection instruments, iv) study design v) how PCK is considered (components of PCK or others).

Theme 1: Subjects and Topics Studied

Among the thirty-one studies, fifteen were about science education (four of them chemistry education and three of them physics education), and again fifteen were about mathematics education. Only one study was about both science and mathematics education. On the other hand, one of the physics education studies was about "Force and Motion", two of the chemistry education study were about the topics of "Chemical Bonding" and "Electrochemistry", five of the mathematics education study were about the topics of "Trigonometry",

"Perimeter and Area", "Subject of Circle", "Functions and Students" and "Algebra".

Theme 2: Profile of the Participants

Among the thirty-one studies, fourteen studies conducted with pre-service teachers and in-service teachers were selected as participants in twelve of the studies. The studies were conducted with high school physics, chemistry, and mathematics teachers. Only one study was conducted with elementary and secondary school teachers together.

Theme 3: Data Collection Instruments

Most researchers did not use only one data collection instrument. Many studies were conducted using multiple data collection instruments. For example, lesson plans, content knowledge tests, interviews, and observation notes were used to collect data.

Theme 4: Study Design

Qualitative approach was used in most studies. However, some studies were conducted using qualitative and quantitative approaches together. Most of the studies were conducted using the mixed approach to provide a more comprehensive understanding of the research. This mixed method was used to be more effective and reliable.

Theme 5: How PCK is Considered (Components of PCK)

There were no studies concerning all components of PCK. Only one component of PCK was studied in two studies. Content knowledge, knowledge of student understanding, and knowledge of instructional strategies were examined the most among the components of PCK. Two of the studies were not focused on the components of PCK. These studies examined the development of PCK.

FINDINGS

PCK Competencies of Preservice and In-service Science and Mathematics Teachers

The findings indicated that the level of preservice teachers' PCK is low (Moh'd et al., 2021). Moreover, results revealed that chemistry teachers perform the lowest in teaching in terms of curricular saliency. According to Moh'd et al. (2022), some preservice

Table 1. Article, sample, and data collection tools

Article	Sample	Data Collection Tools
Moh'd et al. (2022)	Twelve in-service secondary mathematics teachers	Lesson plan documents and teachers' interviews
Aliustaoglu and Tuna (2022)	16 prospective teachers	The lesson plans
Aydeniz and Gürçay (2018)	16 third year pre-service physics teachers	Conceptual test
Moh'd et al. (2021)	69 in-service teachers (34 male and 35 female)	Questionnaires and classroom observation
Murtafiah and Lukitasari (2019)	7 mathematics pre-service teachers	Observation, unstructured interviews, and documentation.
Kristanto et al. (2020)	fifteen pre-service mathematics teachers	CK and PCK test instrument
Minken et al. (2021)	29 teachers	Lesson plans
Boz and Belge-Can (2020)	Three pre-service chemistry teachers	Lesson plans, semi-structured interviews, observations, and field notes
Can (2021)	Volunteered 45 chemistry teachers	Pre-and post-observation interviews and lesson observations
Vladusic et al. (2020)	Sixteen preservice chemistry teachers	Lesson plans and observation notes
Conceição et al. (2021)	Three pre-service teachers	Video recording of LS sessions
Juniati and Siswono (2019)	A prospective teacher	Interview and video analysis
Melo et al. (2020)	A secondary school physics teacher	Descriptive study
Ambusaidi et al. (2021)	1445 randomly selected students	A questionnaire
Van et al. (2018)	Two pre-service chemistry teachers	CK and PCK test instrument and lesson observation checklist
Oztay and Boz (2022)	Two pre-service chemistry teachers	Electrochemistry content test, Content Representation (CoRe), semi-structured interviews, video stimulated recall interviews, classroom observations and field notes.
Ünver et al. (2020)	Twenty preservice secondary mathematics teachers	Videotapes of the groups' microteaching and their lesson plans
Azam (2020)	Four secondary school science teachers	Interview transcripts of conversations with the participant teachers
Spangenberg (2021)	Twelve teachers	Semi-structured one-on-one interviews, lesson plans.
Deniz Yilmaz and Küçük Demir (2021)	10 pre-secondary school in-service mathematics teachers and 10 prospective mathematics teachers	Interviews
Lee et al. (2018)	Four mathematics teachers	Interviews
Aksu (2019)	30 pre-service teachers	Open-ended questions
Sæleset and Friedrichsen (2021)	Six middle-school pre-service teachers	Interviews
Sintema and Marbán (2020)	150 pre-service teachers	Vignettes, MPCK self-concept survey and a pencil and paper test on functions.
Ambusaidi et al. (2020)	1,400 Omani 10th grade students	A questionnaire
Guler and Celik (2021)	155 prospective teachers	Pedagogical content knowledge (APCK) test
Duruk and Akgun (2020)	A single participant	A semi-structured interview.

teachers' designing lesson plan sections have occurred inconsistently. It was determined that the pre-service teachers were not at the desired level in terms of identifying the source of students' mistakes and proposing correct solutions (Aksu, 2019). In addition, according to the outcomes, there was a lack of knowledge of students' understanding and knowledge of instructional strategies, which are the subcomponents of the pedagogical content knowledge of prospective mathematics teachers. In short, prospective teachers are found to be incompetent as regards the necessary mathematical subject matter knowledge Deniz Yilmaz and Küçük Demir (2021). Gender differences in Omani students' perception of the PCK of their science teachers were investigated in another study. The results demonstrated variation in preferences related to the learning environment between male and female students. Male students preferred a competitive environment, while female students preferred a collaborative and open environment (Ambusaidi et al.,

2021). A mapping technique was devised to illustrate science teachers' PCK within stories of teaching "force and motion." A comparative analysis of these illustrations reveals fascinating similarities and differences grounded in individual teacher's subject area background and their specific teaching experiences, according to Azam (2020).

Analysis of the Pedagogical Content Knowledge Development of Prospective Teachers

Some of the studies concluded that prospective teachers showed improvement in each of the components of the PCK at the end of the lesson plan (Aliustaoglu & Tuna, 2022; Conceição et al., 2021; Minken et al., 2021; Vladusic et al., 2020). Moreover, some studies revealed that the PCK of the preservice teacher was developed by micro-teaching lesson study (Boz & Belge-Can, 2020; Murtafiah & Lukitasari, 2019; Ünver et al., 2020). In addition, the results show that the majority of participants made positive improvements to

their initial PCK (Juniati & Siswono, 2019; Van et al., 2018). Participants became more knowledgeable about students' misconceptions, developed improved orientations to teaching, and suggested more responsive instructional and assessment strategies along with more elaborate justifications (Aydeniz & Gürçay, 2018). In another study, the findings underscored the importance of professional development for teachers' pedagogical knowledge in problem posing (Lee et al., 2018). It was recommended more use of student-centered teaching and learning methods such as project-based learning, inquiry-based learning, problem-solving, and role-playing to develop science teachers' PCK (Ambusaidi et al., 2020). The subject matter knowledge of prospective mathematics teachers was developed after taking an elective algebra teaching course according to Guler and Celik (2021).

The Components of PCK

Preservice mathematics teachers' PCK and content knowledge (CK) were tried to measure by using a test instrument. It employed the developmental research method and used students' empirical data to investigate the instrument's validity, objectivity, and reliability (Kristanto et al., 2020; Salakhova et al., 2021). It was found that there was no significant correlative relationship between pre-service secondary teachers' CK and PCK and results further revealed that their knowledge of content and students was weak (Sintema et al., 2020). Moreover, the findings show that four elements of PCK on trigonometry manifest themselves in teachers' practice, namely knowledge of the subject matter, knowledge of teaching strategies, knowledge of students' conceptions, and knowledge of curriculum, but varied in levels of sufficiency (Spangenberg, 2021). In another study, the results concluded that science teaching orientation impeded the interactions between most of the PCK components, and critical incidents were found beneficial to the investigations looking for the interactions between three or more PCK components, in particular (Duruk & Akgun, 2020). Similarly, it investigated the nature of pre-service science teachers' integration between knowledge of students' understanding and instructional strategies and their sources of these integrations. The pre-service science teachers frequently demonstrated the integration of knowledge of students' understanding and instructional strategies, often developing topic-specific strategies (Sæleset & Friedrichsen, 2021).

CONCLUSION AND RECOMMENDATION

This review study examined previous research on PCK in science and mathematics education, and these studies generally addressed participants' PCK in mathematics, physics, and chemistry. There were no studies on biology concepts. Several themes were

identified in these studies, and it was found that pre-service and experienced teachers had different levels of PCK development and progressively developed their components.

Most studies have been conducted with science or mathematics teachers in general, but not on a specific topic. This gap should be addressed by researchers studying science or mathematics education in the context of PCK. PCK studies should be conducted on specific topics related to science and mathematics education. In addition, researchers should prefer experienced teachers because pre-service teachers do not have enough experience and their PCK level is naturally low in general.

In light of the studies in the literature since 2018, some recommendations can be derived:

- Further studies could be conducted with experienced teachers, and students' perceptions of their teachers' PCK should be considered.
- It is recommended that in-service science and mathematics teachers receive training on implementing teacher competencies, especially PCK, in designing lesson plans for effective instructional practice.
- It is important to provide in-service training to implement PCK in teaching practice and improve teaching strategies based on the learner-centered approach to increase teachers' PCK levels.
- Professional development programs can cultivate science and mathematics teachers' PCK to better support them in planning and implementing science and mathematics lessons.
- It has been suggested that lesson plans should be conducted during training programs for prospective science and mathematics teachers.

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REFERENCES

- Aksu, Z. (2019). Pre-service mathematics teachers' pedagogical content knowledge regarding student mistakes on the subject of circle. *International Journal of Evaluation and Research in Education*, 8(3), 440-445. <https://doi.org/10.11591/ijere.v8i3.20250>
- Aliustaoglu, F., & Tuna, A. (2022). Analysis of the pedagogical content knowledge development of

- prospective teachers in the lesson plan development process: 4MAT model. *International Journal of Progressive Education*, 18(1), 298-321.
- Alkis Küçükaydin, M. (2019). A qualitative meta-synthesis of science education studies regarding pedagogical content knowledge. *Journal of Turkish Science Education*, 16(3), 336-349.
- Ambusaidi, A. A., Al-Hajri, F., & Al Mahrooqi, M. (2020). The difference between reality and desirability in science teachers' pedagogical content knowledge as perceived by their students. *Cypriot Journal of Educational Sciences*, 15(5), 1011-1029. <https://doi.org/10.18844/cjes.v15i5.4097>
- Ambusaidi, A., Al-Hajri, F., & Al-Mahrooqi, M. (2021). Gender differences in Omani students' perception of the pedagogical content knowledge of their science teachers as appeared in reality and students' preferences. *Journal of Turkish Science Education*, 18(4), 781-797. <https://doi.org/10.36681/tused.2021.103>
- Aydeniz, M., & Gürçay, D. (2018). Assessing and enhancing pre-service physics teachers' pedagogical content knowledge (PCK) through reflective cores construction. *International Online Journal of Education and Teaching*, 5(4), 957-974.
- Azam, S. (2020). Locating personal pedagogical content knowledge of science teachers within stories of teaching force and motion. *EURASIA Journal of Mathematics, Science and Technology Education*, 16(12), em1907. <https://doi.org/10.29333/ejmste/8941>
- Bayram-Jacobs, D., Henze, I., Evagorou, M., Schwartz, Y., Aschim, E. L., Alcaraz-Dominguez, S., Barajas, M., & Dagan E. (2019). Science teachers' pedagogical content knowledge development during enactment of socioscientific curriculum materials. *Journal of Research in Science Teaching*, 56(9), 1207-1233. <https://doi.org/10.1002/tea.21550>
- Belayneh, A.S. (2021). Science teachers' integrative practices in teaching, research, and community services: The case of three universities in Ethiopia. *Education and Self Development*, 16(2), 10-26. <https://doi.org/10.26907/esd.16.2.02>
- Boz, Y., & Belge-Can, H. (2020). Do pre-service chemistry teachers' collective pedagogical content knowledge regarding solubility concepts enhance after participating in a microteaching lesson study?. *Science Education International*, 31(1), 29-40. <https://doi.org/10.33828/sei.v31.i1.4>
- Can, H. B. (2021). Enacted pedagogical content knowledge profiles of chemistry teachers. *Journal of Educational Issues*, 7(1), 565-583. <https://doi.org/10.5296/jei.v7i1.18643>
- Conceição, T., Baptista, M., & da Ponte, J. P. (2021). Examining pre-service science teachers' pedagogical content knowledge through lesson study. *EURASIA Journal of Mathematics, Science and Technology Education*, 18(1), em2060. <https://doi.org/10.29333/ejmste/11442>
- Deniz Yilmaz, D., & Küçük Demir, B. (2021). Mathematics teachers' pedagogical content knowledge involving the relationships between perimeter and area. *Athens Journal of Education*, 8(4), 361-384. <https://doi.org/10.30958/aje.8-4-2>
- Duruk, Ü., & Akgun, A. (2020). Using real engagement in the active problem-solving model in teaching science: An interpretive pedagogical content knowledge study of an experienced science teacher. *International Online Journal of Education and Teaching*, 7(4), 1741-1772.
- Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. Teachers College Press, Columbia University.
- Guler, M., & Celik, D. (2021). The effect of an elective algebra teaching course on prospective mathematics teachers' pedagogical content knowledge. *International Electronic Journal of Mathematics Education*, 16(2), em0636. <https://doi.org/10.29333/iejme/10902>
- Juniati, D., & Siswono, T. Y. E. (2019). Examining prospective teachers' belief and pedagogical content knowledge towards teaching practice in mathematics class: A case study. *Journal on Mathematics Education*, 10(2), 185-202. <https://doi.org/10.22342/jme.10.2.7326.185-202>
- Kristanto, Y. D., Panuluh, A. H., & Atmajati, E. D. (2020, February). Development and validation of a test instrument to measure pre-service mathematics teachers' content knowledge and pedagogical content knowledge. In *Journal of Physics: Conference Series* (Vol. 1470, No. 1, p. 012008). IOP Publishing. <https://doi.org/10.1088/1742-6596/1470/1/012008>
- Kuznetsova, E.V. (2021). How do students of mathematics relate to their learning? Research into individual and motivational factors. *Education and Self Development*, 16(2), 139-152. <https://doi.org/10.26907/esd.16.2.09>
- Lee, Y., Capraro, R. M., & Capraro, M. M. (2018). Mathematics teachers' subject matter knowledge and pedagogical content knowledge in problem posing. *International Electronic Journal of Mathematics Education*, 13(2), 75-90. <https://doi.org/10.12973/iejme/2698>
- Melo, L., Cañada-Cañada, F., González-Gómez, D., & Jeong, J. S. (2020). Exploring pedagogical content knowledge (PCK) of physics teachers in a Colombian secondary school. *Education Sciences*, 10(12), 362. <https://doi.org/10.3390/educsci10120362>
- Minken, Z., Clarke, A., Marco-Bujosa, L., & Rulli, C. (2021). Development of teachers' pedagogical content knowledge during lesson planning of

- socioscientific issues. *International Journal of Technology in Education*, 4(2), 113-165. <https://doi.org/10.46328/ijte.50>
- Moh'd, S. S., Uwamahoro, J., & Orodho, J. A. (2022). Analysis of mathematics lesson planning framed by the teachers' pedagogical content knowledge. *European Journal of Educational Research*, 11(2), 1161-1182. <https://doi.org/10.12973/eu-jer.11.2.1161>
- Moh'd, S. S., Uwamahoro, J., Joachim, N., & Orodho, J. A. (2021). Assessing the level of secondary mathematics teachers' pedagogical content knowledge. *Eurasia Journal of Mathematics, Science and Technology Education*, 17(6), em1970. <https://doi.org/10.29333/ejmste/10883>
- Murtafiah, W., & Lukitasari, M. (2019). Developing pedagogical content knowledge of mathematics pre-service teacher through microteaching lesson study. *Online Submission*, 13(2), 201-218. <https://doi.org/10.22342/jpm.13.2.7663.201-218>
- Ozden, M. (2008). The effect of content knowledge on pedagogical content knowledge: The case of teaching phases of matters. *Educational sciences: theory and practice*, 8(2), 633-645.
- Oztay, E. S., & Boz, Y. (2022). Interaction between pre-service chemistry teachers' pedagogical content knowledge and content knowledge in electrochemistry. *Journal of Pedagogical Research*, 6(1), 245-269. <https://doi.org/10.33902/JPR.2022.165>
- Sæleset, J. (2021). *Teaching science with students in mind* [Doctoral thesis]. <https://hdl.handle.net/10037/22597>
- Sæleset, J., & Friedrichsen, P. (2021). Pre-service science teachers' pedagogical content knowledge integration of students' understanding in science and instructional strategies. <https://doi.org/10.29333/ejmste/10859>
- Salakhova, V. B., Masalimova, A. R., Belyakova, N. V., Morozova, N. S., Osipova, N. V., & Prokopyev, A. I. (2021). Competitive teacher for higher education: Risk-based models of its development. *Eurasia Journal of Mathematics, Science and Technology Education*, 17(10), 1-12. <https://doi.org/10.29333/EJMSTE/11187>
- Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-22. <https://doi.org/10.17763/haer.57.1.j463w79r56455411>
- Shulman, L. S. (1986) Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15, 4-14. <https://doi.org/10.3102/0013189X015002004>
- Sintema, E. J., & Marbán, J. M. (2020). Pre-service secondary teachers' mathematical pedagogical content knowledge self-concept related to their content knowledge of functions and students. *International Electronic Journal of Mathematics Education*, 15(3), em0598. <https://doi.org/10.29333/iejme/8327>
- Spangenberg, E. D. (2021). Manifesting of pedagogical content knowledge on trigonometry in teachers' practice. *Journal of Pedagogical Research*, 5(3), 135-163. <https://doi.org/10.33902/JPR.2021371325>
- Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education*, 4, 99-110. [https://doi.org/10.1016/0742-051X\(88\)90011-X](https://doi.org/10.1016/0742-051X(88)90011-X)
- Tchoshanov, M., Quinones, M.C., Ibragimova, E., Shakirova, L., & Shakirova, K. (2019). Lower secondary school mathematics teachers' topic-specific content knowledge in the U.S. and Russia. *Education and Self Development*, 14(1), 31-44. <https://doi.org/10.26907/esd14.1.05>
- Ünver, S. K., Özgür, Z., & Güzel, E. B. (2020). Investigating preservice mathematics teachers' pedagogical content knowledge through microteaching. *Journal of Research in Mathematics Education*, 9(1), 62-87. <https://doi.org/10.17583/redimat.2020.3353>
- Usak, M., Masalimova, A. R., Cherdymova, E. I., & Shaidullina, A. R. (2020). New playmaker in science education: COVID-19. *Journal of Baltic Science Education*, 19(2), 180-185. <https://doi.org/10.33225/jbse/20.19.180>
- Usak, M., Ozden, M., & Eilks, I. (2011). A case study of beginning science teachers' subject matter (SMK) and pedagogical content knowledge (PCK) of teaching chemical reaction in Turkey. *European Journal of Teacher Education*, 34(4), 407-429. <https://doi.org/10.1080/02619768.2011.592977>
- Van, L., Mao, S., & Cnudde, V. (2018). Improving pedagogical content knowledge on rational numbers of Cambodian teacher trainers. *Global Education Review*, 5(3), 196-210.
- Vladusic, R., Bucat, R., & Ozic, M. (2020). Evidence of the development of pedagogical content knowledge related to chemical bonding during a course for preservice chemistry teachers. *CEPS Journal*, 10(1), 59-81. <https://doi.org/10.26529/cepsj.783>
- Yusupova, N. G., & Skudareva, G. N. (2020). Ongoing education of math teachers and pisa quality assessment: From professional competence to the mathematical literacy of schoolchildren. *Education and Self Development*, 15(3), 203-214. <https://doi.org/10.26907/esd15.3.17>