J. Korean Earth Sci. Soc., v. 44, no. 4, p. 331–341, August 2023
https://doi.org/10.5467/JKESS.2023.44.4.331
ISSN 1225-6692 (printed edition)
ISSN 2287-4518 (electronic edition)

Exploration of Teacher Pedagogical Content Knowledge (PCK) and Teacher Educator PCK Characteristics in Future School Science Education

Youngsun Kwak[1] and Kyu-dohng Cho[1,2,*]

[1]Department of Earth Science Education, Korea National University of Education, Chungbuk 28173, Korea
[2]Myongji High School, Seoul 03656, Korea

Abstract: The goal of this study was to examine the PCK required for science teachers and PCK required for university teacher educators in terms of school science knowledge, science teaching and learning, and the role of science educators, which are the main axes of science education in future schools, and to explore the relationship between them. This study is a follow-up to a previous stage of research that explored the prospects for changes in schools in the future (2040-2050) in terms of school knowledge, educational methods, and teacher roles. Based on in-depth interviews, qualitative and semantic network analyses were conducted to derive and compare the characteristics of PCK and PCK. As for the main research results, science teacher PCK in future schools should include expertise in organizing science classes centered on convergence topics, expertise in digital platforms and ICT use, and expertise in building a network of learning communities and resources, as part of the expertise of human teachers differentiated from AI. Teacher educators' PCK includes expertise in the research and development of T-L methods using AI, expertise in the knowledge construction process and practice, and expertise in developing preservice teachers' research competencies. Discussed in the conclusion is the change in teacher PCK and teacher educator PCK with changes in science knowledge, such as convergence-type knowledge and cognition-value integrated knowledge; and the need to emphasize values, attitudes, and ethical judgments for the coexistence of humans and non-humans as school science knowledge in the post-humanism future society.

Keywords: Future school, Science teacher, PCK, Teacher educator, Posthumanism, Convergence curriculum

Introduction

Teacher expertise in secondary school subjects, including science, largely consist of subject content expertise and subject-specific expertise, and the teacher's own expertise differentiated from content experts has been defined as Pedagogical Content Knowledge (PCK, hereafter) (Carlson et al., 2019; Gess-Newsome, 2015; Shulman, 1986). Over half a century since Shulman (1986) introduced the PCK concept, scholars of subject education proposed the Refined Consensus Model of PCK (RCM) through two PCK summits at the academic level (Carlson et al., 2019; Gess-Newsome, 2015). PCK is a teacher's practical knowledge base and encompasses teachers' professional knowledge and skills such as teaching orientation, curriculum knowledge, knowledge of student understanding, teaching strategy and assessment knowledge (Gess-Newsome, 2015).

Recent research trends related to PCK in science include analysis of professional expertise and PCK needs of science teachers following the revision of competency-based curriculum (Hong et al., 2019; Kim et al., 2015), and PLC protocol development studies (Jeong et al., 2023; Kwak et al., 2022) to support teacher professional development by PCK areas of science teachers. In particular, recently, new demands for PCK by science teachers are increasing, both inside and outside science teacher education, according to changes in the future society and educational environment (OECD, 2019). Recently, studies have been conducted to explore the development of teacher professionalism in accordance with the demands for changes in future education due to changes in the social environment, such as a sharp decline in the

*Corresponding author: earthsam@sen.go.kr
Tel: +82-2-305-5951, Fax: +82-2-309-7289

school-age population, the demand for teachers' multi-subject teaching competency, and changes in the role and competency of teachers due to the development of intelligence information technology and advanced science and technology (Hong et al., 2019; Kwak, 2022).

According to future education research, future schools in 2045 are characterized by convergence school knowledge that is characterized by trans-boundary, schools on wheels that visit students, and AI teachers who are in charge of knowledge transfer (KICE, 2022). In the era of the 4th industrial revolution characterized by AI, with the world living in the same time zone with COVID-19 as an opportunity, OECD Education 2030 sets the goal of global education to foster 'student agency with transformative competencies', and the recently announced 2022 national-level curriculum in Korea adopts the same educational goal (MOE and KOFAC, 2022). It is necessary to develop the professional expertise of science teachers in Korea to nurture student agency with transformative competencies set by OECD Education 2030. In particular, it is necessary to develop the professionalism of teachers who can educate students as new literacy is required including AI·big data, climate·environmental crisis, inclusive society, human rights sensitivity, etc. according to future society changes.

In addition, Korea is facing a significant turning point in the elementary and secondary school teacher training system due to the rapid decline in the school-age population, the transformative competency and agency of teachers required in post-anthropocentric neo-materialism paradigm, and the transition to an ecological paradigm including ecological transformation education. For example, it can be summarized as the integration of elementary and secondary teacher training institutions, the increase in authority and responsibility of provincial offices of education for teacher training, the introduction of master's course teacher education program (M.Ed. hereafter), and reinforcement of practice in teacher training courses (MOE, 2021).

In particular, it is necessary to identify the professionalism of teacher educators who will be in charge of teacher education, that is, the demand for PCK of teacher educators, along with the establishment of the curriculum and teacher professionalism standards of teacher training colleges (Kim et al., 2015; Kim et al., 2019) as part of the research on the teacher training system reform. In the M.Ed. training system as well as the current undergraduate teacher training system, it is necessary to identify the demand for professionalism of university teacher educators who will be in charge of teacher education.

In this context, this study aims to explore the PCK of teacher educators, which is the expertise that university teacher educators should have, compared to PCK, which is the expertise that secondary school science teachers should have. In the previous stage of this study, the future (2040-2050) school change prospects were explored in terms of school knowledge, teaching and learning, and teacher role (KICE, 2021; 2022). To summarize the research results of the previous stages: (1) Organized megatrends and macrotrends by social field, including STEEP (Social, Technological, Economic, Ecological, Political), which is used as a macroscopic trend analysis method for predicting future society, and based on this, derived the characteristics of future school knowledge for each field, and (2) through two Delphi surveys and expert panel consultations, trends in future school education changes were categorized into school knowledge characteristics, teaching learning, and teacher role, which are the main axes of education (KICE, 2021; 2022).

This study aims to examine the validity of the prospects for changes in school knowledge, teaching learning, and teacher role in science education in future schools, focusing on the three categories constituting the trends of future school education changes confirmed in the previous stage of research, and to compare what is required in terms of teacher PCK and teacher educator PCK in light of the change prospects for each category. In this study, we will derive PCK required for science teachers and PCK required for university teacher educators in terms of school science knowledge, teaching learning, and the

role of instructors, which are the main axes of science education in future schools, and explore the relationship between them.

Methods

In this study, in-depth interviews were conducted with an expert focus group to explore the characteristics and relationship between the PCK required for science teachers (teacher PCK, hereafter) and the PCK required for university science teacher educators (teacher educator PCK, hereafter) in terms of school knowledge characteristics, teaching learning, and teacher role, which are the main pillars of science education in future schools (see Table 3).

Each focus group consisted of 5 veteran science teachers centered on researchers majoring in science education who acted as facilitators of discussion. All of the science teachers who participated in the focus group in-depth interviews were teachers with between 15 and 23 years of teaching experience in master's and doctoral courses at graduate schools, and were equipped with literacy skills for competency-based science curriculum and science education trends, including science and PCK. The science teachers who participated in the focus group in-depth interviews were teachers with between 15 and 23 years of teaching experience, and all were graduate students in master's and doctoral programs. All participants had literacy on competency-based science curriculum and science education trends, including science PCK.

Professors who acted as facilitators in each focus group presented the direction and characteristics of future school science education change in three categories based on the previous stage research (KICE, 2022), discussed teacher PCK that is newly requested in future school science education, focusing on the future school education change prospects, and played the role of facilitator to discuss what the PCK of teacher educators in charge of teacher education is in light of teacher PCK.

In the in-depth interview, the participants divided future school science education into (1) school knowledge of science, (2) teaching and learning of science, and (3) role of science instructor, and discussed the prospects for changes in teacher PCK and science teacher educator PCK for each category. In-depth interviews were conducted 2 to 3 times for each focus group from January to June 2023, and each in-depth interview took 40 to 60 minutes, and all were recorded and transcribed for analysis. Through qualitative analysis, in-depth interview data were coded based on the abductive grounded theory of Strauss & Corbin (1998), and categories were connected or integrated based on the relevance between categories through repeated coding by two researchers. After extracting the main issues based on the final agreed-upon code, it was reviewed whether there was a distorted interpretation by going through a process of cross-examination among researchers.

Table 1. Participants of FG in-depth interviews

	Participants
Group 1	Prof. A, Tr. C, Tr. S, Tr. E, Tr. M, Tr. W
Group 2	Tr. P, Tr. G, Tr. H, Tr. D, Tr. Y, Tr. N

In addition to the qualitative analysis, a semantic network analysis was conducted on the in-depth interview text. Semantic network analysis is a method of confirming the frequency and centrality of text, and is a method of quantitatively showing keywords and links between keywords appearing in text. Using this, it is possible to identify which concepts are distributed in the three PCK areas, centering on secondary science teachers and teacher educators, and the semantic connection structure of concepts.

In the semantic network analysis, data processing such as stop-words (adverbs, prepositions, etc.) processing, case unification, and punctuation removal were performed. using the python-based NLTK library. Afterwards, similar words were grouped together, and words such as education, teacher, and preservice, which were mentioned in their usual meaning, were removed. In the case of teacher educator PCK, 86 keywords with a frequency of 4 times or more were selected out of a total of 360 keywords and visualized using gephi

0.9.4. In the case of teacher PCK, 61 keywords with a frequency of 4 times or more were selected and visualized out of a total of 285 keywords.

Results and Discussion

1. Science knowledge in the future school

Experts agreed that science knowledge and science curriculum knowledge in future schools in the post-humanist era will be given priority to convergence knowledge, context-based knowledge, and meta-knowledge such as the nature or philosophy of science. Experts' diagnoses and prospects for future school science and knowledge discourse and the characteristics of school knowledge are as follows:

First, as the anthropocentric view of knowledge that only humans can produce knowledge has been dismissed, the posthumanist knowledge perspective is emerging as an alternative, and experts predicted that future school students would learn, share, and reproduce knowledge while performing knowledge learning in which human knowledge and AI knowledge are mixed.

According to the prospect of school knowledge, PCK required for science teachers include expertise in converging AI-generated knowledge and human-generated knowledge, understanding of meta-knowledge, and expertise in judging the validity of knowledge produced from AI(KICE, 2021; OECD, 2019). In order to develop such expertise in science teachers, science teacher educators need to have expertise in secondary school curriculum, expertise in science and science education trends, and expertise in various programs for using digital information technology and networking.

Tr. G: Teachers should develop curricula and teaching methods that are appropriate for students to freely reproduce knowledge from their surroundings. Teacher educators should research and disseminate the secondary school curriculum through the convergence of AI knowledge and human knowledge.

Tr. M: Teachers should give students to understand the knowledge construction process. In addition, teacher educators should allow preservice teachers to access knowledge created in the form of post-humanism, which is not human-centered.

Tr. E: Teachers should teach the ability to distinguish correct information from incorrect information in a sea of information. Teacher educators need to strengthen preservice teachers' curriculum content expertise in order to develop teachers with high-level subject-related knowledge who can judge the validity of knowledge produced by AI.

Second, since future learning requires knowledge to be used in learners' lives and ways to use knowledge, it is expected that the production of convergence and complex knowledge between academic areas will be more active in future school knowledge than traditional knowledge in the discipline system.

In this context, it is expected that secondary science teachers will need knowledge about the curriculum of other subjects, STEAM education competencies that combine science and information subjects, and multi-subject teaching competencies (MOE and KOFAC, 2022). Teacher educators should identify the needs of secondary school students as well as pre-service teachers, and knowledge of convergent curriculum. For this, it is expected that university teacher educators will need to expand their knowledge base, such as minors, have the capacity to teach learning as knowledge sharing, and have expertise in linking and expanding knowledge in their major field with other fields.

Tr. S: In constructing knowledge related to students' lives, it is important for teachers to understand the characteristics of students and develop convergence knowledge accordingly. Teachers who are experts in each subject should come together to conduct project-type convergence classes.

Tr. Y: Teachers should effectively present examples of applying the knowledge taught in the science subject to the lives of students. In addition, STEAM education, which combines science and information subjects, should be activated. Teacher educators should develop not only the teacher's content knowledge but also practical knowledge that connects with real life.

Tr. H: Since future knowledge is characterized by cross-border and convergence knowledge, teachers should exchange with teachers of other subjects to develop convergence classes. Teacher educators should train teachers to deal with digital cognitive systems, that is, algorithms and big data, by breaking down the boundaries between disciplines.

Third, science teachers agreed with the prospect that in future schools, contextual knowledge for constructing and generating student-led knowledge, optimized problem-solving methods, and knowledge to find information, that is, know-where, will be emphasized beyond existing methodological knowledge to inquire knowledge beyond 'knowing how' (KICE, 2022).

In this context, PCK required for science teachers include expertise in inquiry for knowledge construction, expertise in identifying student characteristics to design student-led instruction, and expertise in reconstructing the curriculum linking learning and practice. In addition, in order to develop the professionalism of preservice teachers that AI cannot provide, teacher educators need expertise to link major knowledge to practical knowledge through simulation, and expertise to research student-led teaching and learning methods.

Tr. W: Teachers should help students relate the concepts they have constructed to everyday life, and reorganize the curriculum so that students can put what they have learned into practice. Teacher educators should research T-L methods that allow students concept construction, and verify them through collaboration with teachers.

Tr. C: In the era of exploring and producing knowledge, the secondary school system will also change significantly. It is necessary to develop the unique expertise of teacher education that induces demand for major knowledge. Practices and simulations that actually apply expertise and knowledge that AI cannot provide will become important as teacher educators' expertise.

Tr. H: Since the knowledge construction process may be unfamiliar to preservice teachers, teacher educators should provide classes where they can experience the process of building new knowledge through connection, integration, and convergence between knowledge.

Fourth, from a post-humanism perspective, experts predicted that the depletion of earth's resources, global warming, environmental education, and sustainable development education would be further strengthened. Education for sustainable development or ecological education, which deals with coexistence with non-human beings including the natural environment, will be emphasized as the school knowledge of a post-human-centered future intelligent information society.

In this context, PCK required for science teachers include curriculum expertise to link environmental education with science curriculum, expertise in interdisciplinary and convergent environmental education curriculum development, recognition of the role of an agency for global ecology, and expertise in SSI education for the coexistence of humans and AI. In this context, the PCK required for teacher educators include curriculum expertise related to sustainable life, SSI education expertise including climate justice and scientific ethics, and expertise to act as a bridge between science and society.

Tr. Y: When teaching and utilizing AI technology, SSI for the coexistence of humans and AI should also be addressed. Teacher educators should help pre-service teachers understand the characteristics of the posthumanist paradigm, and develop the competency to practice sustainable development education through science education.

Tr. H: Teachers should emphasize ethical judgment as future school knowledge, so they should provide learning opportunities for AI and human coexistence and how to apply bioethics. Through teacher education, teachers should first be able to master human dignity, values, bioethics, and SSI-related education.

Tr. D: Teachers should focus on fostering ethical values, attitudes, and knowledge that are difficult to replace with AI. As mentors, teacher educators should provide insights that relate human life to ecological trends, and design curricula that foster humanities literacy or artistic aesthetics.

2. Science teaching and learning

In relation to science teaching and learning in future schools, experts predicted that students' self-directed learning would be required in a customized way based on digital platforms, metaverse-type virtual learning spaces, and the use of digital information and AI technology. Experts' prospects for future school science T-L methods are as follows:

First, experts predicted that students' self-directed learning would be strengthened by applying online/offline learning methods using information science technologies such as simulation, VR, AR, and AI platforms. With the advent of digital and AI-based T-L methods and tools, various T-L through various channels will be possible in science instruction in future schools.

As the space-time boundary of the 'classroom' gradually disappears, the PCK required for science teachers include expertise in new teaching methods that cross online and offline, and expertise in researching various virtual learning environments. In this context, the PCK required for teacher educators include expertise in developing digital-based education platforms, and expertise in linking digital and coding with science and subject knowledge.

Tr. P: New learning environments in which teachers and students experience T-L activities and interactions that transcend time and space, such as using avatars within a metaverse-type virtual learning environment, will be required. Teacher educators should continue to research how games can be applied in education, and provide a blueprint for what elements can be incorporated into games in education.

Tr. S: Teachers need the ability to boldly challenge and experiment with classes that were previously impossible due to time and space constraints and to research various virtual learning environments. Teacher educators should develop the teaching capabilities of pre-service teachers in the AI digital age through class demonstrations such as augmented reality, virtual reality, metaverse, and hologram contents.

Tr. Y: In the future, convergence with digital information will be inevitable in any field, and science teachers need expertise in linking digital and AI-related competencies with science subjects. Teacher educators are responsible for designing curricula that develop teachers' computer programming and coding competencies, and for certifying their professionalism.

Second, experts predicted that teaching and learning would be personalized and individualized. In addition, AI-based classes would comprehensively manage students' learning histories and provide customized curriculum according to individual learners' learning progress. The use of digital platforms and AI technology will accelerate individualized classes tailored to the needs and demands of individual learners.

In this context, the PCK required for science teachers would include expertise in understanding students, expertise in developing curriculum for student-customized learning, and expertise in individualized instruction (Kwak, 2022). Correspondingly, the PCK required for teacher educators include understanding of schools and students, and system building and support expertise to share good alternatives.

Tr. G: Teachers need knowledge about students because they can guide them in appropriate learning methods based on their understanding of students, and through this, they can achieve more effective educational achievement.

Tr. C: In the school of the future, knowledge will be newly constructed through student agencies, so teachers should organize curricula for individualized learning. Teacher educators should establish and support a system in which teachers can share good alternative methods that can be used in the science curriculum.

Tr. D: As the role of knowledge transfer weakens, teacher expertise is needed for personalized education for each student. Teacher educators should develop student-customized education expertise by allowing preservice teachers to experience individualized learning opportunities.

Third, experts predicted that various collaborative learning beyond time and space would be strengthened through hyper-connected network society and digital

virtual world. That is, teaching and learning through various forms of cooperation beyond physical and temporal constraints, collaborative learning between learners or between learners and instructors, online and offline, will be emphasized as hyper-connected network learning becomes commonplace.

In this context, PCK required for science teachers include expertise in teaching methods that enable student-directed learning, and expertise in teaching methods for knowledge sharing and knowledge exchange. Correspondingly, the PCK required for teacher educators include expertise in teaching methods to develop and provide student-led inquiry-type teaching and learning, and expertise in developing preservice teacher curricula suitable for the teacher's role as a curator.

Tr. G: In order to present tasks and problems that can be approached and solved by students' own learning methods, teachers need expertise in teaching methods. Teacher educators need expertise in teaching methods because they should develop an inquiry-type T-L method that can educate students on their own initiative.

Tr. P: Learning pathways will be diversified, and the T-L method, which emphasizes student agency, will be emphasized. Teachers need pedagogical expertise that enables them to network among students and develop collaborative learning tasks.

Tr. C: In future schools, teachers will have to survive with their own expertise in the commercialization of digital information technology. With the expertise of human teachers differentiated from AI, we need to explore the teacher's role in linking and coordinating between students and instructors, students and learning paths, and digital and physical networking.

3. The Role of Science Instructors

First, experts predicted that future science teachers would have to serve as mentors to support students' scientific lives based on their successful science learning experiences. In addition, future school science teachers will need to change to a role that nurtures students' key competencies, as the traditional teacher expertise of the knowledge delivery type will weaken due to the emergence of substitute teachers called AI (KICE, 2022).

In this context, the PCK required for science teachers include expertise to develop future key competencies, and curriculum design expertise to foster community and inclusiveness. Correspondingly, the PCK required for teacher educators include philosophical knowledge about the knowledge construction process and epistemology, and expertise in developing preservice teachers' research expertise for knowledge construction.

Tr. C: Even after becoming a teacher, you still need to fill in the lack of content knowledge, and this demand will become more urgent in future schools. Teacher educators should provide educational opportunities by utilizing MOOCs, etc., so that teachers can update subject expertise by reflecting the changing trend of science contents.

Tr. S: As the view of knowledge changes along with the development of technology, teacher educators should educate preservice teachers on the philosophical background such as knowledge construction process and epistemology.

Tr. P: Since knowledge, including core competencies, continues to change over time, it is necessary to study changes in the existing and new curriculum, so teachers need knowledge about the curriculum.

Second, experts predicted that in future schools, science teachers would play a stronger role in coaching careers and emotions rather than delivering knowledge. Due to the diversification of the role of science instructors, teacher expertise in various fields will be required, and in this context, science teachers will be required to have collaborative competency to exchange and communicate with other subject teachers or experts in various fields.

Along with the role change from teaching to coaching, the PCK required of science teachers include under-standing of students, role as a stepping stone to connect students and the local community, expertise to build and share information networks, and expertise in team teaching or PLC collaboration. Correspondingly, the PCK required for teacher

educators include expertise in curriculum development that connects subjects and careers, and expertise in activating teacher PLC (Kwak, 2022).

Tr. S: Rather than doing everything on their own, teachers need to leverage their surrounding networks to meet the diverse needs of students, which requires teachers' ability to collaborate. Teacher educators should play a role of bridging between teachers and social institutions and creating a network of educational environments.

Tr. Y: The role of teacher educators will also change from teaching to coaching. Teacher educators should build and activate a curriculum network and information network where teachers can exchange and communicate with experts in various fields.

Tr. W: Since the importance of PLC will be emphasized more in the future, teachers should be open to convergence with other subjects. Teacher educators should develop the ability of teachers to actively participate in PLC, share difficulties in the field and explore solutions through active communication with teachers.

Third, experts emphasized that science teachers need knowledge about big ideas and curriculum trends in related subjects, since future schools will develop and provide the curriculum in a pluralistic and multi-centered way. In addition to the current curriculum reconstructing expertise, expertise in the trend of change and big ideas in related science majors is required.

In this context, PCK required for science teachers will require understanding of the process of big idea change in their major area, and expertise in curriculum design to strengthen students' agency. Correspondingly, the PCK required for teacher educators include various domestic and international curriculum trends and related expertise, reestablishment the role of teachers according to the changing times, and curriculum development expertise for preservice teacher education.

Tr. N: Teachers should understand the process of developing and revising the curriculum in order to develop the story of the curriculum. When teaching the history of science, teachers can naturally deal with experimental methods or philosophy of science, so teachers should also know the history of science.

Tr. C: In the future society, teachers need to develop a curriculum, and developing it at the PLC level will be an alternative. Teacher educators should present various alternative curriculums, such as overseas trends, so that preservice teachers can explore the strengths and weaknesses.

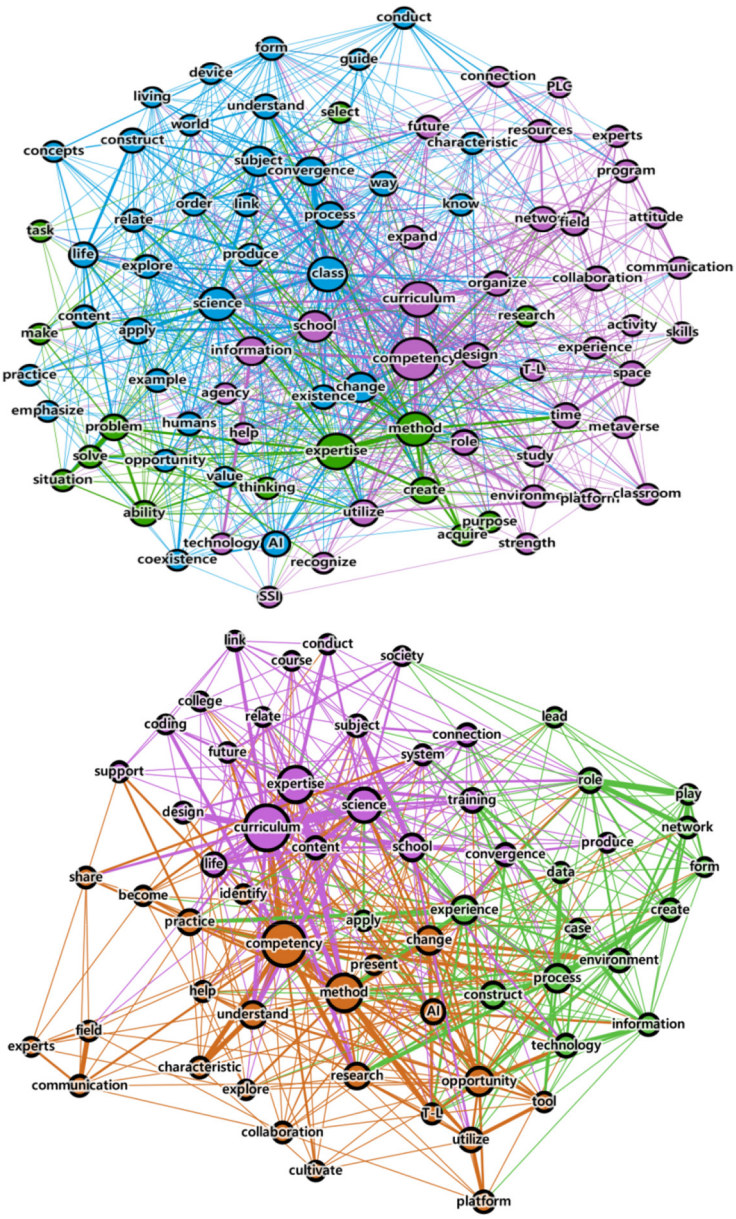
Tr. E: Teachers of future schools should have the ability to develop their own curriculum by integrating various information rather than delivering a set curriculum. Teacher educators need to develop preservice teachers' competencies to understand, interpret, and reconstruct the curriculum.

4. Semantic network analysis

The results of semantic network analysis for the three categories are shown in Fig. 1. In Fig 1, the size of the node indicates the frequency of keyword appearance, and the thickness of the connection reflects the frequency of connection between keywords. The semantic network analysis results are as follows:

First, the scientific knowledge of future schools showed a clear connection around keywords such as 'curriculum', 'competency', 'convergence', and 'subject'. In the case of science teacher expertise, a clear connection appears in [subject-convergence-science-class], [life-understand-construct], and [curriculum-design-competency]. That is, in future school science education, teachers should have expertise in organizing science classes centering on convergence topics, expertise in linking real life and science content, and expertise for problem solving. Correspondingly, as the expertise required of teacher educators, a clear connection was found in [curriculum-expertise-science-content], [design-expertise-curriculum], [science-school-convergence], and [science-expertise-future-society]. That is, science teacher educators need curriculum expertise based on subject knowledge, convergence curriculum expertise, and a role as a bridge between science and society.

Second, as teacher expertise related to science teaching and learning, there is a clear connection in



keyword	freq.
competency	38
expertise	28
curriculum	27
class	26
method	25
science	23
school	20
change	18
subject	18
information	16
convergence	15

keyword	freq.
curriculum	32
competency	30
method	23
expertise	22
science	20
opportunity	14
change	13
experience	13
process	13

Fig. 1. Semantic network analysis results for teacher PCK & teacher educator PCK

[information-technology-competency], [AI-change-method], and [network-resource-program]. This means that science teachers need expertise in digital platforms and ICT use, expertise in changing teaching methods using AI that transcends time and space, and expertise in networking educational resources and programs. For teacher educators, clear connections are found in [competency-characteristic-understand], [research-method-competency], and [method-change-AI-T-L]. That is, teacher educators need expertise in research and development of teaching methods, and expertise in changing teaching and learning methods using AI.

Finally, as for the teacher's role, clear connections appear in [AI-value-humans], [network-resources-PLC], [school-expand-future-connection], and [curriculum-organize-collaboration]. In other words, by utilizing

the expertise of human teachers differentiated from AI, science teachers need expertise in network construction of learning communities and resources, and expertise in organizing curriculum through collaboration. For teacher educators, clear connections appear in [role-play-network], [experience-process-construct], and [research-method-competency]. This suggests that teacher educators need to develop educational environment networks and preservice teachers' research competency.

Conclusion

This study is a follow-up study of the previous stage of research that explored the prospects for changes in schools in the future (2040-2050) in terms of school knowledge, educational methods, and teacher role. In this study, we examined PCK required for science teachers and PCK required for university teacher educators in terms of school science knowledge, science teaching learning, and the role of science instructors, which are the main axes of science education in future schools, and explored the relationship between them.

For this purpose, in-depth interviews with expert focus groups were conducted. Based on in-depth interviews, a qualitative analysis and a semantic network analysis was conducted to analyze the characteristics of teacher PCK and teacher educator PCK. Based on the results, the following conclusions were drawn.

First, in the case of future science knowledge, it will change to integration and linkage between academic areas, and the composition of a convergence curriculum. In particular, convergence knowledge linked to students' personal and community life, such as sustainable development education, and knowledge integrated with cognition and values will be emphasized as science knowledge in future schools. Therefore, science teachers should have expertise in user-centered convergence curriculum design tailored to the local community and students, and teacher educators should build and supply a platform that can share various curriculum through a network organization based on digital information and AI.

Second, in future schools, AI may act as a substitute for science knowledge delivery, and therefore, human science teachers will play a major role in coaching to support career paths, emotions, and successful learning experiences rather than teaching. In this context, science teachers will need expertise such as networking with experts in various fields and cooperation in the form of team teaching or PLC. In addition, Teacher educators should have expertise in exchange and communication through the creation of an educational environment and resource network, and vitalization of the PLC. In particular, for the sustainable development of teachers, the reason for the existence of teacher educators, it is necessary to develop teachers' research expertise in the long term so that they can play a role as clinical educators as researchers.

Third, in the case of future school science teaching and learning, teaching and learning that transcends time and space using advanced science and technology and AI will become commonplace, so science teachers should have expertise in various experiential and realistic teaching and learning methods. In addition, teacher educators need to establish a support system that can share various teaching and learning methods using digital information and AI technology, and develop a curriculum for teacher education suitable for the teacher's role as a knowledge sharer.

Fourth, as part of the countermeasures against the sharp decline in the school-age population, along with the training of science teachers need multi-subject teaching competencies, teachers colleges should actively prepare ways for teachers to advance into areas and activities other than the teaching profession, along with diversification of teacher entry channels. Lastly, it is necessary to emphasize values, attitudes, and ethical judgments for the coexistence of humans and non-humans, including machines, AI, and the natural environment in the post-humanist future society as school science knowledge.

References

Carlson, J., Daehler, K. R., Alonzo, A. C., Barendsen, E., Berry, A., Borowski, A., … and Wilson, C. D., 2019, The refined consensus model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, and A. Boroswki (Eds.), Repositioning pedagogical content knowledge in teachers' knowledge for teaching science (pp. 77-94). Singapore: Springer.

Gess-Newsome, J., 2015, A Model of Teacher Professional Knowledge and Skill including PCK: Results of the Thinking from the PCK Summit. In A. Berry, P. Friedrichsen, and J. Loughran (Eds.), Re-Examining Pedagogical Content Knowledge in Science Education (pp. 14-27). New York: Routledge.

Hong, S., Ahn, Y., and Choi, Y., 2019, Teachers' Teaching Competency Modeling in Future Schooling, Journal of Education & Culture, 25(3), 365-388.

Jeong, E., Kwak, Y., and Lee, K., 2022, A Case Study of School-Level Professional Learning Community using Protocol for Science Inquiry Class. Biology Education, 51(2), 220-235.

KICE, 2021, Prospect of school knowledge and reconstruction of curriculum according to future social megatrends (I). KICE, Jincheon, 747 p. (in Korean)

KICE, 2022, Prospect of school knowledge and restructuring of curriculum according to the future social megatrends (II). KICE, Jincheon, 543 p. (in Korean)

Kim, W., Park, Y., Lee, J., Huh, J., and Kim, M., 2019, A study on teacher training and qualification system reform. MOE and Gyeongin National University of Education, 192 p. (in Korean)

Kim, Y., Park, S., Kim, S., and Lee, W., 2015, Exploring the direction of teacher policy in response to the reorganization of the integrated liberal arts and science curriculum. Korean Education Policy Research Institute and MOE.

Kwak, Y., 2022, Exploring Changes in Science PCK Characteristics through a Family Resemblance Approach. Journal of Korean Society of Earth Science Education, 15(2), 235-248.

Kwak, Y., and Choe, S., 2007, Research on science pedagogical content knowledge (PCK) with the curriculum revision. Seoul: KICE.

MOE and KOFAC, 2022, 2022 Revised Science Curriculum Draft (Final Draft) Development Policy Research Final Report. MOE and KOFAC, 479 p. (in Korean)

MOE, 2021, '2022 Revised Curriculum' General Direction Announcement. Press release (2021.11.24.).

OECD, 2019, OECD Future of education and skills 2030 conceptual learning framework: A series of concept notes. OECD, Paris, 146 p.

Shulman, L. S., 1986, Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4-14.

Strauss, A., and Corbin, J., 1998, Basics of Qualitative Research: Grounded Theory Procedures and Techniques (2nd ed.). Sage Publications, Thousand Oak, CA, USA, 270 p.

Van Driel, J. H., Verloop, N., and deVos, W., 1998, Developing science teachers' pedagogical content knowledge. Journal of Research in Science Teaching, 35(6), 673-695.

Manuscript received: August 2, 2023
Revised manuscript received: August 27, 2023
Manuscript accepted: August 30, 2023