UNDERSTANDING AND SUPPORTING SCIENCE TEACHERS TEACHING OUTSIDE THEIR EXPERTISE: STUDIES OF TEACHERS AND THOSE WHO SUPPORT THEM

by

HARLEEN SINGH

(Under the Direction of Julie A. Luft)

ABSTRACT

Teachers play an important role in student learning. When teachers are assigned to teach outside their expertise, it can prove challenging for them. This dissertation is a step towards understanding how different out-of-field conditions impact science teachers. The first study of the dissertation aims at understanding the development of enacted pedagogical content knowledge (ePCK) of early career teachers teaching out-of-field in their instructional area. The study participants are 17 teachers teaching physical science as a part or all of their teaching assignments during the first three years of their teaching career. Data for this study were collected in the form of classroom observations and semi-structured interviews. The findings from this study indicate that teachers teaching out-of-field show less developed ePCK and show more inconsistencies in their PCK than their in-field counterparts. This study highlights that OOF teachers do not build their instructional practices at the same rate as their in-field counterparts and the need to support teachers teaching outside their expertise. In thinking about supporting science teachers, the second study focuses on being OOF in the area of context. This study is focused on understanding the shifts in the knowledge, practices, and attributes of science coordinators and the resources they draw upon in supporting science teachers during the pandemic. The participants in this study are 15 science coordinators from ten countries. The data for this study consists of semi-structured interviews and follow-up interviews if needed. This study uses the concepts of organizational resources and capital as the framework to understand the experiences of school science coordinators. This study indicates an increase in technology (that was essential for the shift), collaboration, creativity, and interpersonal skills. The majority of the practices and attributes that were important during the pandemic were related to working with people (soft skills). SCs' knowledge, practices, and attributes translated as supports in the form of social and material resources and likely human resources available to the teachers. This study highlights how science coordinators can support teachers as they are out-of-field in their instructional context.

INDEX WORDS: enacted pedagogical content knowledge, out-of-field teaching, teacher support, knowledge, practices, attributes

UNDERSTANDING AND SUPPORTING SCIENCE TEACHERS TEACHING OUTSIDE THEIR EXPERTISE: STUDIES OF TEACHERS AND THOSE WHO SUPPORT THEM

by

HARLEEN SINGH

B.E., Panjab University, India, 1989

B.Ed., Indira Gandhi National Open University, India, 2004

M.Tech, NIIT University, India, 2015

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2021

© 2021

Harleen Singh

All Rights Reserved

UNDERSTANDING AND SUPPORTING SCIENCE TEACHERS TEACHING OUTSIDE THEIR EXPERTISE: STUDIES OF TEACHERS AND THOSE WHO SUPPORT THEM

by

HARLEEN SINGH

Major Professor: Julie A. Luft
Committee: Georgia Wood Hodges
Dorothy Yazidah White

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
August 2021

ACKNOWLEDGEMENTS

I thanks and acknowledge all the people who have encouraged, supported, and guided me through the awesome journey of my doctoral program. Firstly, I would like to thank my major professor Julie A. Luft for her invaluable guidance, patience, and encouragement. This dissertation would not have been possible without her guidance. My heartfelt thanks to me amazing committee members, Georgia Wood Hodges and Dorothy Yazidah White. To Brooke Whitworth for her guidance and feedback for this study. I also take this opportunity to thank my family and friends for their unconditional support through thick and thin. My lovely daughters Anna and Sanjana. I could not have done this without you by my side.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

"The quality of an education system cannot exceed the quality of its teachers and their work" (Schleicher, 2011, p. 1). Teachers play an essential role in improving and maintaining teaching and learning as they implement research-based curriculum and instructional strategies. Research indicates that gaps in teacher quality can influence student achievement (Berry et al., 2009; Darling-Hammond, 2000; Stronge, 2013). Consequently, compromising teacher quality would have a direct influence on student achievement. Teacher quality includes the knowledge, skills, abilities, and dispositions of teachers to work with others and support the learning and success of all students (Mitchell et al., 2001). Teachers are required to have a deep knowledge of the content they teach (Mitchell et al., 2001) and knowledge of pedagogy and context.

Several conditions can lead to teachers teaching outside their expertise. One condition is when there is a mismatch between the certification and qualification of a teacher, and their teaching assignment, also called out-of-field (OOF) teaching (Ingersoll, 1998). In addition, teachers may be outside their expertise when teaching specific topics within their subject area they may not have expertise in. When teachers find themselves in new instructional settings, this can also result in them being outside of their expertise. Recently, the COVID-19 pandemic has resulted in teachers working in an online setting in which they are unfamiliar with the tools, processes, and procedures.

When teachers are assigned to teach outside their expertise, there are many ways in which their instruction is compromised. Napier et al. (2020) found that OOF teachers struggle with selecting appropriate instructional activities, enacting the content, and ensuring proper laboratory techniques and safety. OOF teachers may misrepresent the content, or they may not select the best representation. (Du Plessis, 2015) observed OOF teachers struggle in responding to their students as they likely lacked the confidence to engage students in challenging subject matter, avoided in-depth discussions, and occasionally provided students with incorrect feedback. Similar observations were made by Sanders et al. (1993), who looked at the classroom practices of three experienced teachers. When teaching OOF, the teachers relied more on teacher talk, textbooks and occasionally made errors. In addition, they tended to focus on the middle group in the classroom, thereby ignoring the needs of the high achieving students and those with special needs.

Being out-of-field in an instructional setting is, unfortunately, a frequent event in classrooms. The Teaching and Learning International Survey (TALIS) reported that students half of the teachers in the Organization for Economic Co-operation and Development (OECD) countries do not use technology frequently or always for project work and classwork (Schleicher, 2020). In science education, research indicates that teachers may not use digital technologies in classroom practices towards developing high-level thinking and reasoning skills (Rodrigues, 2006). Teachers may lack the confidence and competence to use ICT in instruction. Fear of failure may make teachers anxious and adversely influence their confidence and motivation to use ICT for instruction (Balanskat et al., 2006; Beggs, 2000; Osborne & Hennessy, 2003).

This study constitutes two manuscripts that depict different aspects of being out-of-field. The first manuscript focuses on how the content knowledge of a teacher impacts his or her instruction. Especially, this study looks at the development of enacted Pedagogical Content Knowledge (ePCK) among early-career physical science teachers inside and outside their specialization. The second manuscript reports on the experiences of science coordinators, who are supporting science teachers who were moved to an online environment during the COVID-19 pandemic. Together the two studies add to the scholarship on the impact of out-of-field teaching of science teachers.

Background About Teachers Teaching Outside Their Expertise

Teaching assignments are demanding when they do not align with teachers' expertise. One such situation can be the challenge of teaching content of which they do not have adequate knowledge. The mismatch between the subject to be taught by a teacher and their specialization or certification is called out-of-field (OOF) teaching (Ingersoll, 1998) or teaching across specializations (TAS) (Hobbs & Törner, 2014). OOF teaching has been identified as a concern from countries worldwide, including the U.S., Australia, South Africa, United Kingdom, Ireland, Turkey, and Korea.

In the U.S., approximately 54.6% of middle-grade students and 21.3% of high school students in public schools are taught science by teachers outside of their expertise (Rahman et al., 2017). Shah et al. (2019) found that 69% of physics teachers, 59% of chemistry teachers, and 43% of biology teachers teach these subjects without either a major/minor or certification, or both major/minor and certification in the assigned subject. However, the true extent of OOF teaching is masked by the absence of consistency in defining and reporting OOF teaching among states. Varying criteria within the definition of OOF teaching include teachers lacking adequate certification in the assigned subject area, number of credit hours in the content area, and the amount of instructional time spent teaching OOF in a day (U.S. Department of Education, 2018).

OOF teaching is an equity issue. Less qualified and OOF teachers are more likely to teach low-income schools than high-income schools, and more in rural and urban schools than in suburban schools (Ingersoll & Curran, 2004; Ingersoll, 1998; Nixon et al., 2017; Qin & Bowen, 2019). Teachers placed in small rural districts could face additional problems due to isolation from other teachers of the subject, expert teachers, and limited PD opportunities (Ríordáin et al., 2019). These schools have a few science teachers who may be responsible for teaching all science subjects. They may teach a combination of subjects and grades, with the assignments changing from year to year.

Despite the significant presence of OOF teaching, very little research exists on the issue (Hobbs & Törner, 2019). Across the research that does exist, OOF teaching is known to influence both teachers and students adversely. OOF teachers have reported feelings of low self-efficacy, powerlessness, low self-confidence in their ability to fulfill assigned roles, lack of satisfaction in achieving student outcomes, high rates of workplace fatigue, and influences their science teacher identity (Du Plessis et al., 2015; Du Plessis, 2015; Du Plessis et al., 2017; Fitchett et al., 2019; Hobbs, 2013). When teachers experience these areas, it negatively influences their perceptions of themselves and their ability and effectiveness as teachers (Steyn & Du Plessis, 2007). One such OOF teacher reported, "Actually, we are out-of-field, out of everything, out of confidence…" (Du Plessis et al., 2017, p. 150).

Variations in teaching assignments can also adversely influence teachers and students. There can be changes in a teacher's responsibility, such as changing grade levels, changing OOF assignments from year to year, or changing syllabus. Changes in the work environment can be associated with declining enjoyment and confidence of OOF teachers (Du Plessis et al., 2019) and renovicing experienced teachers (Blazar, 2015; Sanders et al., 1993). When teachers are assigned temporary subjects without confirming if they would be teaching the same subject the following year, it puts the teachers' in transit' (Du Plessis et al., 2015, p. 6). Grade level reassignments or 'within school churn' are well documented in elementary education (Baker & Boruch, 2015; Blazar, 2015). These teachers find themselves underprepared in the same manner as OOF teachers at the secondary level. Variations in OOF teaching assignments have the potential to impact the measure of OOF teaching (Ingersoll, 2019), classroom instructional practices of the teachers (Du Plessis et al., 2015; Sanders et al., 1993), and the support mechanisms that help OOF teachers adapt to the new field (Hobbs, 2013). These could prevent teachers from developing the required knowledge and practices.

Another challenge faced by OOF teachers includes the non-availability of professional development (PD) opportunities tailored to OOF teachers' needs (Faulkner et al., 2019). PD implemented for OOF teachers may be specifically designed for them or may be general to all teachers. PD programs for in-field teachers may not be suitable for OOF teachers since their requirements are different from their in-field counterparts (Faulkner et al., 2019). Support in the form of PD programs and working with teams of teachers are successful in helping OOF teachers adapt to their new field (Hobbs, 2012). In-service professional development programs (Ogodo, 2019; Vale, 2010), alternate teaching arrangements including sharing of expertise by teachers at other schools, participation in cross marking assignments (Hobbs, 2012), in-service content courses (Crisan & Rodd, 2017), and a collaborative learning environment (Beswick et al., 2016) have helped support OOF teachers in various ways.

OOF teaching is problematic because it has the potential to inhibit high-quality science teaching and ultimately influence student learning. In their synthesis of research, (Wayne & Youngs, 2003) found that subject specialist knowledge and teacher certification were significantly associated with higher student achievement. When teachers were OOF, their students did not perform as well. Similarly, Darling-Hammond (2000), Dee and Cohodes (2008), and Goldhaber and Brewer (2000) found that students assigned to in-field teachers performed better than those assigned to their OOF counterparts. These studies used different approaches to reveal the importance of subject qualifications and student learning. Darling-Hammond (2000) used data from School and Staffing Surveys (SASS) and the National Assessment of Educational Progress (NAEP), while Dee and Cohodes (2008) used matched pair data to explore how the same set of students performed when assigned to two teachers with different subject qualifications.

The recognition of this problem has been noted by U.S. policymakers and resulted in standards for highly qualified teachers through the No Child Left Behind (NCLB) act of 2001 and the Every Child Succeeds Act (ESSA) of 2015. ESSA requires that low-income and minority students are not served disproportionately by inexperienced, ineffective, or OOF teachers (U.S. Department of Education, 2017). States are required to document the occurrence of OOF teaching and ensure equal access of quality teachers to all students. The ESSA gives states flexibility in defining and reporting OOF teaching according to their own needs. As a result, there is no consistency in the way states define and report OOF teaching. Unfortunately, teachers continue to experience OOF teaching in various contexts because of loopholes in the policy.

Teaching Outside Their Expertise During the COVID-19 Pandemic

Another challenging situation that requires teachers to teach outside their expertise has been experienced during the COVID-19 pandemic. Due to the physical closing of schools, teachers worldwide have shifted instruction to various forms of distance learning. Distance learning involves providing access to learning when the teacher and learner are separated by space and time (Moore et al., 2011). It may involve using print-based learning material, broadcasting radio, television programs, or through web-based platforms using social media or learning management systems (UNESCO, 2020b). As of March 2020, 191 countries have closed educational institutions countrywide. Since February 2020, this has left almost 1.58 billion learners out of educational institutions at some time. This figure represents almost 91.3% of the world's enrolled student population. Sixty-three million teachers at the elementary and secondary levels have been affected worldwide (UNESCO, 2020a).

The sudden shift in instruction from a well-structured school system to distance learning can be challenging for many teachers. Teachers who made this quick transition may not have had sufficient knowledge of the pedagogy of teaching science using technology or other forms of distance learning. The immediate and unforeseen shift gave them little time to acquire or upgrade their information and communication technologies (ICT) skills. The term ICT refers to the range of hardware, software applications, and information systems (Park et al., 2009). Schools had little time to prepare teachers for this unprecedented and swift transition in the format of teaching and learning. Teachers shifted from integrating some use of technology in classroom science instruction to entirely planning, implementing, and assessing instruction using distance learning. Some teachers may be skilled in using computer-based technologies for teaching and learning, making the transition to online learning relatively easy. For other teachers, this may pose a difficult challenge (Winzenried et al., 2010).

The effectiveness of distance learning depends on various aspects of the preparedness of teachers, schools, and students. Technological readiness includes the capacity of the schools to provide content remotely to the students, which they should be able to access from their homes. This access can be through online digital learning platforms or radio and television. Content readiness includes the readiness of teachers to create curricular content. Many schools lack the resources and local expertise to create readily available content for students for distance learning. Pedagogical readiness indicates the readiness of teachers to design and facilitate online and radio/television-based instruction (UNESCO, 2020b). However, many teachers do not have the requisite training and preparation for this. Monitoring and evaluation readiness include the capacities of the teacher to monitor distance student learning, keep track of student access to instruction, student engagement, the progress of students, and evaluate student learning (UNESCO, 2020b).

School leaders play an important role in supporting and improving science teachers' regular implementation of teaching and learning in K-12 schools. They create an environment that helps teachers implement change, consequently influencing student achievement (Banilower et al., 2007; Desimone, 2009; Guskey, 2002). The success of teachers in adapting new and reform-based modes of instruction depends largely on the support they receive from school leaders. Science coordinators at the school and the district level influence the teachers' instructional practices by providing subject-specific day-to-day support and PD for the teachers (Whitworth & Chiu, 2015). Their role becomes even more valuable in the present day health crisis of the COVID-19 pandemic as they help support school science teachers to adopt, adapt to, and succeed in teaching in a new format of instruction.

The shift in instruction format from in-person to online instruction during the pandemic has been abrupt and unplanned. In order to ensure continuity of education, many schools have rushed to adopt online instruction. This shift has taken place with minimum resources and time available to the teachers. With the change in methods and modes of delivery of instruction, teachers’ needs have changed rapidly. We know that effective online teaching is a consequence of careful instructional design and planning. Well-designed online education provides agency, flexibility, responsibility, and choice to the learners. It provides the learners with an alternative and flexible option for learning (Bozkurt & Sharma, 2020). This careful design process may be missing when instruction shifts online without adequate preparation.

OOF Teaching in Science

The *Next Generation of Science Standards* (NGSS) (Lead States, 2013) emphasizes the combination of science, technology, engineering, and mathematics into STEM and STEAM (including art) instruction that provides a multi and interdisciplinary approach to learning. The standards emphasize that high-quality STEM education should be available to all students. Teachers are expected to adopt reform-based science and engineering practices in their instruction and use STEM concepts to identify and solve complex problems.

Unfortunately, new and many science teachers may not have the expertise or sufficient training to implement aspects of the standards. One area pertains to the three dimensional instruction, and another area pertains to the integration of mathematics or engineering with science (Freeman et al., 2017). For example, in California, implementing the new standards that emphasize three dimensional learning is found to be uneven. About a quarter of the districts have reported a shortage of teachers credentialed to teach the NGSS. Most teachers are not well-prepared to teach the new standards as they face training gaps (Gao et al., 2018). NGSS advocates teaching STEM subjects in an integrated way in the context of the real world. Engineering is an implicit part of the NGSS, with different aspects of engineering represented in the three dimensions of the framework (Lead States, 2013). For many K-12 teachers, engineering as content and pedagogy is a new idea. Most teachers do not have adequate training in engineering and feel unprepared to teach it (Brophy et al., 2008; Haag & Megowan, 2015; Purzer et al., 2014). The lack of adequate content knowledge and pedagogical knowledge can likely make teachers OOF. Teaching science subjects OOF can influence the use of science and engineering practices since these practices may look different in different subjects. For example, modeling in physics may be used in a predictive way, unlike in biology, where it may be used in a descriptive way (Krell et al., 2015).

OOF Teaching as an Equity Issue

OOF teaching has a differential impact, with low-income and diverse students experiencing greater numbers of teachers who are not qualified in their instructional areas. (Ingersoll, 2001; Ingersoll, 2019) concludes that OOF teaching frequently occurs in schools and fields that suffer from teacher shortages. There is a disparity in the distribution of qualified teachers both within and between schools in the US, resulting in some students experiencing more OOF teaching than others (Clotfelter et al., 2005; Qin & Bowen, 2019). This disparity has led to inequality in student achievement (Thiemann, 2018). Less qualified and OOF teachers are more likely to teach low-income schools than high-income schools, and more in rural and urban schools than in suburban schools (Ingersoll & Curran, 2004; Ingersoll, 1998; Nixon et al., 2017; Qin & Bowen, 2019) and more in schools with a larger number of English language learners (Nixon et al., 2017). Within schools, OOF teachers are more likely to teach classes with a larger number of low-income students (Clotfelter et al., 2005; Qin & Bowen, 2019). Across schools, students in middle grades are more likely to be assigned to OOF teachers (Banilower et al., 2007; Nixon et al., 2017), and within a high school, 9th graders are more likely to be taught by OOF teachers (Hill & Dalton, 2013).

Online Learning as an Equity Issue

Online education adopted by schools worldwide has brought the digital divide to the forefront. Both teachers and students experience this divide. Digital inequality is the difference in material, cultural, and cognitive resources essential for making good use of ICT (OECD, 2015). Access to infrastructures like computers, mobile devices, internet connection, and bandwidth are not available uniformly to learners across communities and countries. For example, in 2018, in Africa, around 60% of young people did not have access to the internet compared to 4% in Europe (UNESCO, 2020c). This digital divide is at times more within countries and economies than between countries. For example, in Mexico, the gap in access to computers between advantaged and disadvantaged groups was at least 75% (OECD, 2015). In the United States, 5 million households with children in the age group of 6 to 17 did not have a broadband connection at home (Horrigan, 2015). This created a situation called the homework gap, leaving these students at a clear disadvantage as high school students cannot complete their homework or get lower grades (McLaughlin, 2016).

The second digital divide can result from issues of equal opportunities. The term second-order digital divide refers to non-material resources that influence learners' ability to use ICT tools to their full advantage (DiMaggio et al., 2004). When teachers experience this type of digital inequity, it has the potential to translate to their students. The quality of learners' online experience is influenced by their skill and education level, the type of device used, family income, gender, and availability of content in regional languages. In addition, the unavailability of new technologies can cause gaps in experience. We know that ICTs become more universally available over time, seemingly bridging the divide. However, new tools, technologies, and services are primarily available to the socio-economically advantaged populations, reinforcing their privileges (Hargittai & Hsieh, 2013).

Purpose of the Study

The two studies will be a step towards understanding how beginning OOF teachers develop their knowledge and practices of teaching science and how they can be supported to adapt to their changing work environment. We know that OOF teaching is likely to continue in the near future for various reasons like teacher shortage, high rates of teacher turnover, and misassignment of teachers. It is essential to understand how beginning teachers develop their knowledge of teaching.

This study also helps understand the role of school science coordinators in the context of schools shifting to distance education due to different disasters (e.g., pandemics, natural disasters). The study will help understand school science coordinators' meaningful and significant experiences in helping science teachers design and implement instruction using distance learning during the COVID-19 pandemic. In particular, the study investigates the shift in the knowledge, practices, and attributes of school science coordinators and the resources they drew upon as they worked supporting teachers during the pandemic. As schools shift back to face-to-face instruction post-pandemic, education systems may not be the same as before. Consequently, the role of school leaders will remain crucial and in flux as they work supporting science teachers.

Overview of the Study

This dissertation recognizes the importance of understanding and supporting teachers who work outside their expertise. The qualitative research project explores the potential impact of being OOF on the development of ePCK of early-career science teachers and the shift in the role of science coordinators in supporting science teachers in using a novel format for teaching during the COVID-19 pandemic. The two studies help understand and identify the variation in beginning teacher development and ways to support science teachers when they teach outside their expertise.

The first manuscript is titled "The development of ePCK of newly hired in-field and out-of-field teachers during the first three years of their teaching." This study is a longitudinal cross-case study and asks the following question:

How does the ePCK of in-field and OOF physical science teachers develop over the first three years of their teaching careers?

The study explores the potential impact of teaching outside of one's field of expertise (out-of-field teaching). The conceptual framing for this study lies in the refined consensus model. Teachers use ePCK in their practice. It consists of knowledge and skills that guide all aspects of instruction. ePCK is unique to a particular concept or aspect of the discipline, a setting, and the students' individual needs (Carlson et al., 2019). The study examines the development of ePCK of OOF physical science teachers in their first three years of teaching. The components of PCK investigated include the knowledge and skills related to conceptual teaching strategies and student understanding of science. The study follows seventeen newly hired teachers teaching in and outside their field of expertise during the first three years of their teaching careers. The participating teachers are categorized as varying degrees of in-field and OOF, depending on their content area background, teaching assignment, and part of the day spent teaching in or OOF. The data collected includes semi-structured interviews, classroom observations of the teachers, and artifacts from the classroom like assignments and handouts. The study's findings show that early career OOF physical science teachers showed less developed ePCK and displayed more inconsistencies in their ePCK than their in-field counterparts. The findings also reveal a fluctuating ePCK for most in-field and OOF teachers, expressing the tentative nature of emerging ePCK. This study has implications for school leaders and those who prepare and support newly hired teachers.

The second manuscript is titled "Experiences of school science coordinators while supporting teachers during the COVID-19 pandemic: An international study”. This qualitative study explores school science coordinators' meaningful and significant experiences at the secondary school level during the COVID-19 pandemic. This study asks the following questions:

1 How did the knowledge, practices, and attributes of science coordinators over the world before and during the COVID-19 pandemic change as they worked to support teachers?

2 What resources did they draw upon in supporting their teachers? How did this impact their work?

The participants in the study are science coordinators at the school or district level from ten countries, including Canada, Chile, Mainland China, India, Kenya, Pakistan, Turkey, United States, Taiwan, and Vietnam. One or two participants were selected from each country, making a total of 15 participants. An international context helps understand the situation from a global perspective. Data are collected in the form of semi-structured interviews and follow-up interviews if needed. Data were analyzed thematically, using two cycles of coding. The study has implications for supporting science teachers in the near future as the physical opening of schools remains uncertain in many parts of the world, in school closures during circumstances like natural disasters and snow days, and for preparing and supporting science teachers continue to use their learnings from the pandemic as they shift back to the in-person format.

Overview of the Chapters

Chapter 2 contains the manuscript titled “The development of ePCK of newly hired in-field and out-of-field teachers during the first three years of their teaching.” This paper is published in a special issue titled “Teaching out-of-field: Challenges and possibilities for teacher education” in the *European Journal of Teacher Education (EJTE)*. The qualitative longitudinal cross-case study examines the potential impact of teaching out-of-field. It explores the development of enacted ePCK of teachers teaching in-field and OOF. The study uses the refined consensus model as the theoretical framework (Carlson et al., 2019). ePCK is the form of PCK that teachers use in their practice and is visible in the teachers’ planning, teaching, and reflection. Findings from the study reveal variations in the development of ePCK between in-field and OOF teachers and the fluctuating nature of ePCK. Finally, Implications of the study are discussed.

Chapter 3 contains the manuscript titled "Experiences of school science coordinators while supporting teachers during the COVID-19 pandemic: An international study". This paper is in review for publication in *The Journal of Disciplinary and Interdisciplinary Science Education Research (DISER).* The qualitative study aims to understand the shift in school science coordinators' knowledge, practices, and attributes and the resources they drew upon as they supported science teachers during the COVID-19 pandemic. Participants of this study include 15 science coordinators from 10 countries. An international context helps understand the problem from a global perspective. Findings from the study reveal technology as a knowledge and practice, practices of collaboration and communication, and creativity and interpersonal attributes of science coordinators provided social and material resources to teachers during the pandemic. The majority of the practices and attributes that were important during the pandemic were related to working with people (soft skills). The implications of the study are discussed.

Chapter 4 of the dissertation is the concluding chapter, wherein the two studies are brought together in discussing the contribution to the field, implications of the research, and the future research plan that stems from the findings of these manuscripts.

References

Baker, J., & Boruch, R. (2015). Ambient positional instability among Ohio math and science teachers: 2008 to 2014.

Balanskat, A., Blamire, R., & Kefala, S. (2006). The ICT impact report. *European Schoolnet, 1*, 1-71.

Banilower, E. R., Heck, D. J., & Weiss, I. R. (2007). Can professional development make the vision of the standards a reality? The impact of the national science foundation's local systemic change through teacher enhancement initiative. *Journal of Research in Science Teaching, 44*(3), 375-395. https://doi.org/https://doi.org/10.1002/tea.20145

Beggs, T. A. (2000). Influences and Barriers to the Adoption of Instructional Technology.

Berry, B., Daughtrey, A., & Wieder, A. (2009). Collaboration: Closing the Effective Teaching Gap. *Center for teaching quality*.

Beswick, K., Fraser, S., & Crowley, S. (2016). "No wonder out-of-field teachers struggle!" [Article]. *Australian mathematics teacher, 72*(4), 16-20.

Blazar, D. (2015). Grade assignments and the teacher pipeline: A low-cost lever to improve student achievement? *Educational Researcher, 44*(4), 213-227.

Bozkurt, A., & Sharma, R. C. (2020). Emergency remote teaching in a time of global crisis due to CoronaVirus pandemic. *Asian Journal of Distance Education, 15*(1), i-vi.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing Engineering Education in P-12 Classrooms [Article]. *Journal of Engineering Education, 97*(3), 369-387. https://doi.org/10.1002/j.2168-9830.2008.tb00985.x

Carlson, J., Daehler, K. R., Alonzo, A. C., Barendsen, E., Berry, A., Borowski, A., Carpendale, J., Chan, K. K. H., Cooper, R., Friedrichsen, P., Gess-Newsome, J., Henze-Rietveld, I., Hume, A., Kirschner, S., Liepertz, S., Loughran, J., Mavhunga, E., Neumann, K., Nilsson, P., Park, S., Rollnick, M., Sickel, A., Schneider, R. M., Suh, J. K., van Driel, J., & Wilson, C. D. (2019). The refined consensus model of pedagogical content knowledge in science education. In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77-94). Springer.

Clotfelter, C. T., Ladd, H. F., & Vigdor, J. (2005, 2005/08/01/). Who teaches whom? Race and the distribution of novice teachers. *Economics of Education Review, 24*(4), 377-392. https://doi.org/https://doi.org/10.1016/j.econedurev.2004.06.008

Crisan, C., & Rodd, M. (2017). Learning Mathematics for Teaching Mathematics: Non-Specialist Teachers' Mathematics Teacher Identity. *Mathematics Teacher Education and Development, 19*(2), 104-122.

Darling-Hammond, L. (2000). Teacher quality and student achievement. *Education policy analysis archives, 8*, 1.

Dee, T. S., & Cohodes, S. R. (2008). Out-of-Field Teachers and Student Achievement:Evidence from Matched-Pairs Comparisons. *Public Finance Review, 36*(1), 7-32. https://doi.org/10.1177/1091142106289330

Desimone, L. M. (2009). Improving Impact Studies of Teachers' Professional Development: Toward Better Conceptualizations and Measures. *Educational Researcher, 38*(3), 181-199. https://doi.org/10.3102/0013189x08331140

DiMaggio, P., Hargittai, E., Celeste, C., & Shafer, S. (2004). Digital Inequality: From Unequal Access to Differentiated Use. In K. M. Neckerman (Ed.), *Social inequality* (pp. 355-400). New York:Russell Sage Foundation.

Du Plessis, A., Carroll, A., & Gillies, R. M. (2015). Understanding the lived experiences of novice out-of-field teachers in relation to school leadership practices. *Asia-Pacific Journal of Teacher Education, 43*(1), 4-21.

Du Plessis, A. E. (2015). Effective education: Conceptualising the meaning of out-of-field teaching practices for teachers, teacher quality and school leaders. *International Journal of Educational Research, 72*, 89-102.

Du Plessis, A. E., Carroll, A., & Gillies, R. M. (2017). The meaning of out-of-field teaching for educational leadership. *International Journal of Leadership in Education, 20*(1), 87-112.

Du Plessis, A. E., Hobbs, L., Luft, J. A., & Vale, C. (2019). The out-of-field teacher in context: The impact of the school context and environment. In *Examining the Phenomenon of "Teaching Out-of-field"* (pp. 217-242). Springer.

Faulkner, F., Kenny, J., Campbell, C., & Crisan, C. (2019). Teacher Learning and Continuous Professional Development. In L. Hobbs & G. Törner (Eds.), *Examining the Phenomenon of "Teaching Out-of-field": International Perspectives on Teaching as a Non-specialist* (pp. 269-308). Springer Singapore. https://doi.org/10.1007/978-981-13-3366-8_11

Fitchett, P. G., McCarthy, C. J., Lambert, R. G., Eyal, M., Playfair, E. C., & Dillard, J. B. (2019). Examining teacher stress-vulnerability in the US secondary school context. *Educational Review*, 1-24.

Freeman, A., Becker, S. A., & Cummins, M. (2017). *NMC/CoSN Horizon Report: 2017 K-12 Edition*. https://www.learntechlib.org/p/182003/.

Gao, N., Adan, S., Lopes, L., Lee, G., & Public Policy Institute of, C. (2018). *Implementing the Next Generation Science Standards: Early Evidence from California*.

Goldhaber, D. D., & Brewer, D. J. (2000). Does Teacher Certification Matter? High School Teacher Certification Status and Student Achievement. *Educational Evaluation and Policy Analysis, 22*(2), 129-145. https://doi.org/10.3102/01623737022002129

Guskey, T. R. (2002, 2002/08/01). Professional Development and Teacher Change. *Teachers and Teaching, 8*(3), 381-391. https://doi.org/10.1080/135406002100000512

Haag, S., & Megowan, C. (2015). Next Generation Science Standards: A National Mixed-Methods Study on Teacher Readiness [Article]. *School Science & Mathematics, 115*(8), 416-426. https://doi.org/10.1111/ssm.12145

Hargittai, E., & Hsieh, Y. P. (2013). Digital inequality. In W. H. Dutton (Ed.), *The Oxford handbook of internet studies*. Oxford University Press.

Hill, J. G., & Dalton, B. (2013). Student Math Achievement and Out-of-Field Teaching. *Educational Researcher, 42*(7), 403-405. https://doi.org/10.3102/0013189x13505682

Hobbs, L. (2012). Teaching out-of-field: Factors shaping identities of secondary science and mathematics [Article]. *Teaching Science: The Journal of the Australian Science Teachers Association, 58*(1), 21-29.

Hobbs, L. (2013). Teaching 'out-of-field'as a boundary-crossing event: Factors shaping teacher identity. *International journal of science and mathematics education, 11*(2), 271-297.

Hobbs, L., & Törner, G. (2014). Taking an international perspective on "Out-of-field" teaching: Proceedings and agenda for research and action from the 1st Teaching Across Specialisations (TAS) Collective Symposium. TAS Collective. *Zugriff am, 4*, 2016.

Hobbs, L., & Törner, G. (2019). Teaching out-of-field as a phenomenon and research problem. In *Examining the Phenomenon of "Teaching Out-of-field"* (pp. 3-20). Springer.

Horrigan, J. B. (2015). *The numbers behind the broadband 'homework gap'*. Pew Research Center. https://www.pewresearch.org/fact-tank/2015/04/20/the-numbers-behind-the-broadband-homework-gap/

Ingersoll, R., & Curran, B. K. (2004). Out-of-field teaching: The great obstacle to meeting the "highly qualified" teacher challenge. *Washington, DC: NGA Center for Best Practices Issue Brief.*

Ingersoll, R. M. (1998). The problem of out-of-field teaching. *The Phi Delta Kappan, 79*(10), 773-776.

Ingersoll, R. M. (2001). The Realities of Out-of-Field Teaching [Article]. *Educational Leadership, 58*(8), 42.

Ingersoll, R. M. (2019). Measuring out-of-field teaching. In *Examining the Phenomenon of "Teaching Out-of-field"* (pp. 21-51). Springer.

Krell, M., Reinisch, B., & Krüger, D. (2015, 2015/06/01). Analyzing Students' Understanding of Models and Modeling Referring to the Disciplines Biology, Chemistry, and Physics. *Research in Science Education, 45*(3), 367-393. https://doi.org/10.1007/s11165-014-9427-9

Lead States, N. (2013). *Next generation science standards: For states, by states*. National Academies Press. https://doi.org/doi:10.17226/18290

McLaughlin, C. (2016). *The Homework Gap: The 'Cruelest Part of the Digital Divide*. NEA Today. https://www.nea.org/advocating-for-change/new-from-nea/homework-gap-cruelest-part-digital-divide

Mitchell, K. J., Robinson, D. Z., Plake, B. S., & Knowles, K. T. (2001). *Testing teacher candidates: The role of licensure tests in improving teacher quality*. ERIC.

Moore, J. L., Dickson-Deane, C., & Galyen, K. (2011). e-Learning, online learning, and distance learning environments: Are they the same? [Article]. *Internet & Higher Education, 14*(2), 129-135. https://doi.org/10.1016/j.iheduc.2010.10.001

Napier, J. B., Luft, J. A., & Singh, H. (2020). In the classrooms of newly hired secondary science teachers: The consequences of teaching in-field or out-of-field. *Journal of Science Teacher Education, 31*(7), 802-820.

Nixon, R. S., Luft, J. A., & Ross, R. J. (2017). Prevalence and predictors of out-of-field teaching in the first five years. *Journal of Research in Science Teaching, 54*(9), 1197-1218. https://doi.org/10.1002/tea.21402

OECD. (2015). *Students, Computers and Learning*. https://doi.org/doi:https://doi.org/10.1787/9789264239555-en

Ogodo, J. A. (2019, 2019/08/18). Comparing Advanced Placement Physics Teachers Experiencing Physics-Focused Professional Development. *Journal of Science Teacher Education, 30*(6), 639-665. https://doi.org/10.1080/1046560X.2019.1596720

Osborne, J., & Hennessy, S. (2003). *Literature review in science education and the role of ICT: Promise, problems and future directions* (Vol. 6). Futurelab London, United Kingdom.

Park, H., Khan, S., & Petrina, S. (2009). ICT in Science Education: A quasi-experimental study of achievement, attitudes toward science, and career aspirations of Korean middle school students. (8), 993.

Purzer, Ş., Moore, T. J., Baker, D., & Berland, L. (2014). Supporting the Implementation of NGSS through Research: Engineering.

Qin, L., & Bowen, D. H. (2019). The distributions of teacher qualification: A cross-national study. *International Journal of Educational Development, 70*, 102084.

Rahman, T., Fox, M. A., Ikoma, S., & Gray, L. (2017). Certification Status and Experience of US Public School Teachers: Variations across Student Subgroups. NCES 2017-056. *National Center for Education Statistics*.

Ríordáin, M. N., Paolucci, C., & Lyons, T. (2019). Teacher professional competence: What can be learned about the knowledge and practices needed for teaching? In *Examining the Phenomenon of "Teaching Out-of-field"* (pp. 129-149). Springer.

Rodrigues, S. (2006). Pedagogic practice integrating primary science and elearning: The need for relevance, recognition, resource, reflection, readiness and risk. *Technology, Pedagogy and Education, 15*(2), 175-189.

Sanders, L. R., Borko, H., & Lockard, J. D. (1993). Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching, 30*(7), 723-736.

Schleicher, A. (2011). Lessons from the world on effective teaching and learning environments. *Journal of Teacher Education, 62*(2), 202-221.

Schleicher, A. (2020). The impact of covid-19 on education insights from education at a glance 2020. *Retrieved from oecd. org website: https://www. oecd. org/education/the-impact-of-covid-19-on-education-insights-education-at-a-glance-2020. pdf.*

Shah, L., Jannuzzo, C., Hassan, T., Gadidov, B., Ray, H. E., & Rushton, G. T. (2019). Diagnosing the current state of out-of-field teaching in high school science and mathematics. *PloS one, 14*(9), e0223186.

Steyn, G., & Du Plessis, E. (2007). The implications of the out-of-field phenomenon for effective teaching, quality education and school management. *Africa Education Review, 4*(2), 144-158.

Stronge, J. (2013). *Effective teachers= student achievement: What the research says*. Routledge.

Thiemann, P. (2018). *Inequality in Education Outcomes: The Role of Sorting among Students, Teachers, and Schools*. Lund University.

U.S. Department of Education. (2017). *Every Student Succeeds Act (ESSA)*. https://www.ed.gov/essa

U.S. Department of Education. (2018). *ESSA Consolidated State Plans*. https://www2.ed.gov/admins/lead/account/stateplan17/index.html

UNESCO. (2020a). *COVID-19 education response: Preparing the reopening of schools: resource paper*. https://unesdoc.unesco.org/ark:/48223/pf0000373401

UNESCO. (2020b). *Distance learning strategies in response to COVID-19 school closures*. https://unesdoc.unesco.org/ark:/48223/pf0000373305?posInSet=2&;queryId=N-8ea77989-29de-4ff3-997c-eaddc678be5b

UNESCO. (2020c). *Some implications of COVID-19 for remote learning and the future of schooling*. https://unesdoc.unesco.org/ark:/48223/pf0000373229?posInSet=1&queryId=5524bd15-de9f-4f24-8353-520e83707466

Vale, C. (2010). Supporting "out-of-field" teachers of secondary mathematics. *Australian mathematics teacher, 66*(1), 17-28.

Wayne, A., J, & Youngs, P. (2003). Teacher Characteristics and Student Achievement Gains: A Review [research-article]. *Review of Educational Research, 73*(1), 89-122.

Whitworth, B. A., & Chiu, J. L. (2015). Professional Development and Teacher Change: The Missing Leadership Link. *Journal of Science Teacher Education, 26*(2), 121-137. https://doi.org/10.1007/s10972-014-9411-2

Winzenried, A., Dalgarno, B., & Tinkler, J. (2010). The interactive whiteboard: A transitional technology supporting diverse teaching practices [Article]. *Australasian Journal of Educational Technology, 26*(4), 534-552. https://doi.org/10.14742/ajet.1071

CHAPTER 2

DEVELOPMENT OF EPCK OF NEWLY HIRED IN-FIELD AND OUT-OF-FIELD TEACHERS DURING THE FIRST THREE YEARS OF THEIR TEACHING

Singh, H., Luft, J.A., and Napier, J. Published in *European Journal of Teacher Education (2021), 1-16.* Reprinted here with permission of the publisher.

Abstract

This study explores the potential impact of teaching outside of one's field of expertise (out-of-field teaching). This longitudinal cross-case study examines the development of enacted pedagogical content knowledge (ePCK) of in-field and out-of-field (OOF) physical science teachers in their first three years of teaching. The components of PCK investigated include the knowledge and skills related to conceptual teaching strategies, and student understanding of science. Seventeen newly hired teachers teaching in and outside their field of expertise participated in the study. The data collected included semi-structured interviews and classroom observations of the teachers. The study's findings show that early career OOF physical science teachers exhibited less developed ePCK and showed more inconsistencies in their ePCK than their in-field counterparts. The findings also revealed that ePCK fluctuated for most teachers, representing the tentative nature of emerging ePCK. This study has implications for administrators and those who prepare and support newly hired teachers.

Keywords: Pedagogical Content Knowledge, Out-of-field teaching, Secondary school teachers, Beginning teachers, Physical science

Introduction

The mismatch between a teacher's area of expertise and teaching assignment is known as out-of-field (OOF) teaching (Ingersoll 1998). In the United States (US), OOF teaching occurs in both middle and high schools and across the core academic subjects of English, science, mathematics, and social studies (Baldi, Warner-Griffin, and Tadler 2015). Approximately 54.6% of middle-grade students and 21.3% of high school students in the US are taught by teachers who are outside of their expertise in science (Rahman et al. 2017). These students are often in settings designated as high-poverty schools, which means a significant number of the students qualify for free or reduced cost meals. These settings are known for frequent teacher turnover, and as a result, teachers are often inexperienced and have minimum academic qualifications (Jerald and Ingersoll 2002; Rahman et al. 2017).

OOF teaching has been shown to influence teachers' classroom instruction and experiences. For example, Du Plessis (2015) reported a "dysfunctional learning space" in OOF teachers' classrooms. She found that OOF teachers lacked the confidence to engage students in challenging subject matter and tended to avoid in-depth discussions. Similar observations were made by Sanders, Borko, and Lockard (1993), who looked at three experienced teachers' classroom practices in both in-field and OOF conditions. They found that when the teachers were in-field, they created productive learning environments. Other studies of OOF teachers have reported feelings of inadequacy, stress, and isolation (Du Plessis et al. 2015; Du Plessis, Carroll, and Gillies 2017) and susceptibility to high rates of fatigue in the workplace (Fitchett et al. 2019).

One important issue related to OOF teaching is the demand it puts on beginning teachers. Researchers have identified myriad problems faced by beginning teachers, including isolation

(Rosenholtz 1989), stress (Fitchett et al. 2019), and the emotions of frustration, uncertainty, and confusion (Zepeda and Mayers 2001). These problems are compounded when newly hired teachers are OOF, because they lack both the experience and knowledge to navigate the demands of teaching. This situation may result in unintended consequences in their development as teachers.

An important area to consider is a teacher's pedagogical content knowledge (PCK). Initially, PCK was a blend of subject matter knowledge (SMK) and pedagogical knowledge (PK) (Shulman 1987). Over time, the PCK model has evolved to focus on the concepts, topics, or aspects found in the teaching of a discipline. Within this PCK model is enacted pedagogical content knowledge (ePCK), which consists of the knowledge and skills utilized by a teacher in a particular setting to teach a particular topic or aspect of the discipline (Carlson et al., 2019). Unfortunately, little is known about the ePCK of teachers. The ePCK perspective is important because it may provide insights into the ways newly hired in-field or OOF teachers build their instructional knowledge and skills.

To understand the potential influence of OOF teaching on the development of newly hired teachers' ePCK, this study followed a group of science teachers during their first 3 years. The 17 physical science teachers had different in-field or OOF assignments. Qualitative methods were used to describe the differences and development of their ePCK. This study specifically asked the question, "How does the ePCK of in-field and OOF physical science teachers change over the first 3 years of their teaching careers?"

Framing and Literature

The conceptual framing for this study resided in the refined consensus model (RCM), which has emerged as the prevailing model of PCK (Carlson et al. 2019). This model varies from earlier PCK models in identifying three distinct forms of PCK (Carlson et al. 2019). The collective PCK (cPCK) is the specialized professional knowledge held by a group of educators. Professional PCK (pPCK) is the personal reservoir of knowledge and skills that a teacher holds, which the teacher may not reveal. ePCK is what practitioners use in their practice. It consists of knowledge and skills that guide all aspects of instruction, and it is unique to a particular concept or aspect of the discipline, a setting, and the students' individual needs. ePCK is considered to be at the center of the RCM and takes a practitioner perspective (Carlson et al. 2019).

The situated nature of ePCK means that it is visible in a teacher's planning, teaching, and reflection (Carlson et al. 2019). In-the-moment plan-teach-reflect episodes result in teachers generating new ePCK, which comes from their reservoir of pPCK. These two knowledge bases influence each other, as one is the enactment and the other is the supporting background. Often, ePCK is tacit and explicit for the teacher. As support, pPCK has strong, weak, or emerging connections to ePCK.

Within the RCM, there are five components for measuring science teachers' PCK. Of these, two were essential in this study when examining the ePCK held by teachers. The first, knowledge and skills related to conceptual teaching strategies, includes the teacher selecting and using appropriate teaching strategies and representations. The second, knowledge and skills related to students' understanding of science*,* includes the teacher identifying and acknowledging variations in student learning and eliciting and assessing student misconceptions and difficulties associated with the presented topic (Chan, Rollnick, and Gess-Newsome 2019).

Literature Review

Consequences of OOF teaching

Worldwide, researchers have determined that teachers positively affect student achievement (e.g., Azigwe et al. 2016; Chu et al. 2015). Often, the learning experienced by students is a result of the teacher's qualifications (e.g., Dee and Cohodes 2008; Wayne and Youngs 2003). More importantly, sustained contact with knowledgeable teachers can contribute to students' academic success (e.g., Darling-Hammond 2000; Wayne and Youngs 2003). For example, the research synthesis by Wayne and Youngs revealed that, over a period of time, students had higher achievement gains in mathematics when their teachers were certified to teach mathematics. Berry, Daughtrey, and Wieder (2009) reinforced the importance of teacher qualifications in finding that students achievement scores fluctuated when they experienced teachers who were not qualified in their subject area.

Even with the recognition that teacher qualifications are important, OOF teaching still occurs in many schools. When teachers are placed in settings that do not utilize their expertise, consequences are found not only for the students but for teachers too. Sharplin (2014), for instance, found that incongruence between the teachers' qualification or experience and their teaching assignments contributed to their dissatisfaction with their work. The OOF teachers in Sharplin's study reported feeling powerless in their school setting, having low self-efficacy and self-confidence, and experiencing difficulty building relationships with their students. Other scholars have reported similar findings (Du Plessis 2015; Fitchett et al. 2019; Hobbs 2013; Steyn and Du Plessis 2007). OOF teachers have also been found to lack the confidence to engage students in challenging subject matter, to avoid in-depth discussions, and to rely heavily on teacher talk and textbooks (Du Plessis 2015; Sanders, Borko, and Lockhard 1993).

Most studies pertaining to OOF science teachers focus on their instruction. Napier, Luft, and Singh (2020), for example, conducted a comparative study of newly hired in-field and OOF physical science teachers. They found the OOF teachers to be at a higher risk of using isolated instructional scientific practices and low-level science instruction when compared to their in-field counterparts.

Sanders, Borko, and Lockard (1993) looked at three experienced science teachers' classroom practices in both in-field and OOF conditions. When teaching OOF, the teachers relied more on teacher talk and textbooks and occasionally made errors. The OOF teachers were observed lacking confidence in engaging students in challenging subject matter. They also focused on the middle-level students in the classroom, thereby ignoring the high-achieving students and those with special needs. While teaching in-field, these teachers answered student questions, linked discussion with content, and were willing to change the flow of the lesson to support student learning.

PCK and ePCK in Science

Many studies have focused on science teachers' PCK. These studies have utilized different models to portray PCK. Models based on the work of Shulman (1986, 1987), Grossman (1990), and Magnusson, Krajcik, and Borko (1999) suggest that a teacher's subject matter knowledge is transformed to PCK during instruction. During this transformation, PCK emerges as useful knowledge for teachers (Gess-Newsome, 1999). Other scholars like Marks (1990), Cochran et al. (1993), Hashweh (1987), and Loughran, Mulhall, and Berry (2008) proposed that subject matter knowledge is an integral part of PCK and evolves over time. Recently, Kind and Chan (2019) added to the discussion of PCK models by recognizing the importance of a teacher's prior experiences. These experiences, which range from historical learning opportunities in science to imitating more experienced teachers, can influence the construction of a teacher's PCK (regardless of whether it is transformative or evolving).

More recently, PCK has been contemplated through the RCM (Carlson et al. 2019). The need to recognize the disciplinary topics within SMK and the different forms of PCK held by teachers prompted the revision of prior PCK models to the RCM. Within the model are three different forms of PCK: cPCK, pPCK, and ePCK. Studies that use this model have been focused on pPCK and ePCK, with a teacher's classroom work related to ePCK and the underlying reservoir of knowledge and skills related to pPCK. ePCK is considered a dynamic form of knowledge because it is closely related to a teacher's interactions with the students in the classroom. These interactions can consist of, for instance, recognizing students' ideas, rewording their questions to address student confusion, or reacting to unexpected situations in the classroom (Alonzo, Kobarg, and Seidel 2012; Park and Oliver 2008). ePCK is also related to the planning and reflection on teaching, which emphasize the teaching of students (Carlson et al. 2019).

Studies are emerging regarding the relatively new constructs of ePCK and pPCK. Most of the studies are focused on describing ePCK or pPCK (e.g., Coetzee, Rollnick, and Gaigher 2020; Mazibe, Coetzee, and Gaigher 2020). Mazibe, Coetzee, and Gaigher, for instance, compared how teachers represented ePCK and described their PCK. They found that the teachers' reported PCK did not necessarily reflect their ePCK, with ePCK often equal to or less detailed than the reported PCK. Other studies explored how ePCK and pPCK can be impacted by factors in the school environment (e.g., Carpendale and Hume 2019; Hanuscin et al. 2020). These studies articulated ePCK or pPCK and determined how it is or is not developed. Carpendale and Hume, for example, implemented a teacher study group that focused on the teaching of a disciplinary topic. They found that their teachers benefited from reflective discussions about their teaching and advanced their ePCK. Hanuscin et al. (2020) examined differences in the sources and nature of elementary teachers' pPCK. They revealed how pPCK was changed as teachers were moved to different grade levels, which required different SMK.

Among newly hired teachers, the studies have been focused on PCK in general. From these studies, researchers have found that the PCK of newly hired teachers was influenced by instructional materials and by their work in classrooms (Luft et al. 2015). However, studies about PCK specifically have conflicting conclusions about the quality and presence of PCK. Some authors (Lee et al. 2007; Luft et al. 2011; Monte-Sano and Budano 2013) have reported that PCK changes significantly in quality during early years of teaching, while others have reported that PCK does not change in the first years of teaching (Friedrichsen et al. 2009).

Methodology

A longitudinal cross-case study was designed to explain the development and variation of ePCK among in-field and OOF newly hired secondary science teachers. Looking at in-field and OOF teachers as cases can bring out the similarities and differences between cases and help build a deeper understanding and explanation of the development of ePCK. This study attempted to provide a rich contextual understanding of the research problem, and the results are not prescriptive. A cross-case analysis helps increase the potential for generalizability or transferability of the findings (Miles, Huberman, and Saldaña 2020).

Setting

This study was conducted at a time when high quality science teaching involved students making sense of science phenomena (National Research Council 1996, 2000). This view is still valued today in current science reforms in the US (see NGSS Lead States 2013). This orientation toward science instruction aspires to have science teachers consider the ideas of their students. By recognizing their students' ideas about science phenomena, teachers can engage students in learning opportunities that allow them to challenge and construct their knowledge of science concepts and abilities to engage in science. Students should have opportunities that include asking questions related to science phenomena, collecting and analyzing data, constructing and revising models, and making explanations from data that include claims and evidence. This orientation toward science teaching was valued in this study.

Participants

The participants in the study were 17 newly hired secondary science teachers in the US Southwest, Midwest, and East Coast regions. They were a purposeful sample (Bogdan and Biklen 2003), which came from a larger study on beginning secondary science teachers (see Luft et al. 2011). The sample consisted of teachers who taught physics or physical science as some part or all of their teaching assignments. A physics course covered physics topics, while a physical science course covered a combination of physics, chemistry, and often earth and space science. A majority of the participants taught in public schools in urban areas that varied in the number of English language learners (ELLs) and the number of students receiving free and reduced lunches (an indicator of poverty in the US).

The teachers in this study were placed in one of three categories each year, which were based upon the subject of their degree and teaching certificate and their teaching assignment. Most teachers fell in Categories 1 and 3. An overview of these teachers is found in Table 2.1.

Data collection

Two types of data were collected during the study: classroom observations and reflective semistructured interviews. Park (2019) suggested using classroom observations and interviews to identify elements of ePCK. Classroom observations, in the form of participant observations, involved observing the instructional practices of the teachers. Classrooms were observed four

Table 2.1

Demographics of participating teachers (N=17)

Teacher	% ELL	% FRL	Degree subject	Degree type	Subjects taught Year 1	Subjects taught Year 2	Subjects taught Year 3	Level of OOF Year 1	Level of OOF Year 2	Level of OOF Year 3
Sandra	13	59	Physics	B.S., M.Ed.	Phy Astr	Phy Astr	Phy Astr	1	1	1
Beth	N/A	7	Physics	B.S., M.Ed.	Phy	Phy Sc	Phy Sc	1	1	1
Jack	1	9	Physics	B.S., M.Ed.	Phy Sc	Phy Sc	Phy Sc	1	1	1
Carl	1	14	Physics	B.S., M.Ed.	Phy Sc	Phy Sc	Phy Sc	1	1	1
Jessica	5	21	Chemistry	B.S., Post-bac	Phy Sc Chem	Phy Sc Chem	Phy Sc Chem	1	1	1
Barb	1	28	Chemistry	B.S.	Phy Sc Chem	Phy Sc Chem	Phy Sc Chem	1	1	1
Lok	8	32	Chemistry	B.S., Post-bac	Phy Sc	Phy Sc	Phy Sc	1	1	1
Caitlin	1	0	Biochemistry	B.S.	Phy	Phy Chem	Phy Chem	3	2	2
Jennifer	6	33	Biology	B.Ed.	Phy Sc Chem	Phy Sc Chem	Phy Sc Chem	3	3	3

Teacher	% ELL	% FRL	Degree subject	Degree type	Subjects taught			Level of OOF		
					Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Demetri	33	45	Biology	PhD	Phy Sc Bio Earth Sc Chem	Bio Chem	Bio Chem	3	1	1
Marrie	19	19	Biology	B.S., M.Ed.	Gen Sc	Chem Gen Sc	Gen Sc	3	3	3
Tina	9	9	Biology	B.A., Post-bac	Phy Sc	Phy Sc Bio	Phy Sc Bio	3	1	2
Steve	6	20	Biology	B.S., M.Ed.	Phy Sc Bio	Phy Sc	Phy Sc	2	3	3
Caleb	30	82	Biology	B.S., Post-bac	Phy Sc	Phy Sc	Phy Sc	3	3	3
Mandisa	1	1	Biology	B.S., Post-bac	Phy Sc	Bio	Chem Bio	3	1	2
Danielle	2	27	Other	B.A., M.Ed.	Gen Sc	Gen Sc	Gen Sc	3	3	3
James	3	32	Other	B.A., M.Ed.	Phy Sc	Gen Sc Bio	Bio	3	3	3

Note: Degree type: B.S. = Bachelor of science, B.A. = Bachelor of arts, B.Ed. = Bachelor's in education, M.Ed. = Master's in education, Post-bac = Postbaccalaureate, PhD = Doctor of Philosophy. Subjects: Astr = Astronomy, Bio = Biology, Chem = Chemistry, Earth Sc = Earth science, Gen Sc = General science, Phy = Physics, Phy Sc = Physical Science. Level of OOF: 1 = completely or mostly in-field, 2 = equally in-field and OOF, 3 = mostly or completely OOF. % ELL = Percent of students who are English language learners, % FRL = Percent of students receiving free and reduced lunch.

times during each year of the study. The observations captured the actions of the teachers, the lesson topic and its enactment, interactions of the teacher and the students, the general atmosphere of the class, and the comfort level of the teacher handling the instructional material. This observational process was guided by Bogdan and Biklen (2003). Artifacts like electronic slides and instructional materials used in the class were also collected at the time of the observation. These artifacts provided additional information about the teachers' instruction and how they decided to represent the instructional topic to their students.

PCK interviews were done two times a year, at the beginning of the school year and the end of the school year. The PCK interviews were designed by Lee et al. (2007) and probed the instructional decision-making process of the teachers and explored how the teachers planned a lesson on a disciplinary topic. Two focal areas guided the interview: (a) teachers' thinking about their students, which included teachers' contemplation of their students' prior knowledge, their considerations about the students' various approaches to learning, and their thoughts about students' difficulties with specific science concepts; and (b) teachers' thinking about instructional strategies used in science, which focused on the teachers' consideration and potential use of practices associated with doing science and representations of the content to scaffold learning (Lee et al. 2007). These areas were captured by having the teachers discuss a specific lesson they taught, which they felt went well in terms of student learning. As the teacher discussed the lesson, the interviewer specifically asked probing questions about student learning and instructional design. These interviews provided insights into the decision making of the teacher (ePCK). The interviews lasted 30-45 minutes and were ultimately transcribed.

Data analysis

The data were analyzed qualitatively. Analysis of these data began with a progressive review of interviews, observations, and materials for each teacher over the 3 years of collected data. In the first cycle of coding, the data were coded structurally, which helps compare the similarities, differences, and relationships between comparable segments (Saldaña 2015). Codes such as Misconceptions and Student Difficulties were used to identify the data segments to be further analyzed in depth. Initially, the research team members (authors of this paper) coded data working individually. When sections were coded, two researchers came together to compare their codes, discuss any data that were not coded similarly, and come to an agreement about the codes (as recommended in Saldaña 2015). While the codes were noted, the research team members also made memos about potential findings. Merriam and Merriam (2009) and Clarke and Braun (2017) suggested that major trends be noted in analytic memos during the analysis process. The codes and memos were essential in the second cycle of coding.

In the second cycle of data analysis, an effects matrix was developed to help identify the findings (as recommended in Miles, Huberman, and Saldaña 2020). This matrix was framed by the categorization of the teacher (for example, Category 1 or Category 2) over 3 years and the different areas that may have influenced their ePCK over time. As a result, each cell of the matrix noted, for instance, their teaching context, their instruction, their thoughts about science, and their considerations for student learning. Direct quotes, summary phrases, and references to artifacts and observations were listed in the cells. These data reflected PCK during teaching and during their reflective accounts.

The research team then examined the data iteratively to determine the teachers' ePCK within their different teaching assignments. This process involved comparing and contrasting the cells in the matrix to answer the research question. As the themes were constructed, disconfirming evidence was sought out (Merriam and Merriam 2009). Themes were crafted that were responsive to the research question and were inclusive of teachers' ePCK and instruction. Complementing these themes were the construction of relationship diagrams, which suggested the connections of the particular events and patterns pertaining to the instructional setting of the teacher (as in Miles, Huberman, and Saldaña 2020). The final themes are summaries of findings pertaining to the teachers in their OOF or in-field teaching assignments over time.

In this analysis process, triangulation occurred through the involvement of several researchers, the use of multiple data sources, and the collection of data over time. This triangulation contributed to the validity of the conclusions (Merriam and Merriam 2009) and helped enhance the trustworthiness of the study (Miles, Huberman, and Saldaña 2020).

Findings

Based on the analysis of data, changes occurred in the teachers' ePCK. The following themes describe how teachers attended to students and presented science differently over time when they were in-field and OOF.

Theme 1: The 1st-year OOF physics teachers had less-developed ePCK and showed more inconsistencies between their ePCK compared to their in-field counterparts.

When compared to their in-field peers, OOF teachers struggled with their understanding and enactment of the content. This lack of understanding cascaded into their decisions about how to represent the content to students and how they considered student understanding. For example, Jennifer was completely OOF as she taught a physical science course to high school students. Throughout the year, she struggled with unfamiliar content, which required extra time learning the content she would be teaching (Interview 2). She commented that real-life examples were difficult for her to identify, and it was challenging to develop different ways to represent the covered topic (Observation 1_2). Her lesson on constant velocity demonstrated her limited understanding of the topic. During the lesson, she did not differentiate between speed and velocity and used these terms interchangeably. The students struggled to understand these ideas and repeatedly asked questions about speed and velocity, like “How does this graph describe speed?” Jennifer pointed out a component on the graph, but it was not related to speed (Observation 1_2).

In contrast, in-field teachers showed high levels of ePCK. Jack, an in-field teacher, designed laboratory work where he encouraged students to develop and test their hypotheses through experimentation (Interview 1). Throughout many of his lessons, he provided students with opportunities to test their hypotheses, redesign their laboratories, and reenact their experiments (Observations 1_2 and 1_3). Similarly, Sandra, an in-field teacher, demonstrated the effect of forces in motion by dropping a soda bottle filled with water and then putting a hole in the bottle and dropping the bottle (the water does not leave the bottle). She had students hypothesize what would happen before the demonstration. After the demonstration, students reasoned about their observations and formed an analogy relating the falling bottle to a moving elevator. The students developed and tested their hypothesis by investigating their own weight when moving up and down in an elevator (Observation 1_2).

Significant differences were also found in terms of how in-field and OOF teachers viewed student knowledge and their ability to select and enact science instruction. In-field teacher Carl, for instance, recognized the misconceptions of students during the lessons and tried to dispel them but admitted that at times it was difficult (Interview 1). For example, during a lesson about magnets, he found that students did not understand magnetic fields and could not explain how they were configured around different arrangements of magnets. In contrast, OOF teachers struggled to acknowledge student misconceptions and to plan coherent lessons. James, an OOF teacher, said he was not sure of his students' misconceptions; hence, he did not plan for them. Tina, who was also OOF and taught physical science, mentioned that her approach to addressing student misconceptions involved generating all possible questions that were related to the topic and misconceptions (Interview 1).

Another difference pertained to the laboratories of the teachers. OOF teachers enacted highly structured laboratories or activities that did not allow students to make sense of phenomena. For example, James' students experimented to find the speed of a moving toy car (Observation 1_4). They followed step-by-step instructions and collected data without understanding the concept associated with the car activity. As a result, most students just copied data from their group members, which resulted in graphs that involved little evaluation or examination of the data (Observation 1_4). James indicated that he rarely provided students opportunities to make sense of the phenomena, as the students worked only for a short period of time and often needed direct instructions (Interview 2).

In the area of understanding student difficulties, most in-field teachers were able to consider student difficulties while planning the lessons. For instance, Jack consistently recognized that students had difficulty graphing data, especially while choosing appropriate increments and identifying dependent and independent variables. In planning to support his students' learning, he developed complete lessons that allowed his students to understand the meaning behind graphs. On the other hand, Catlin (OOF) acknowledged that she was still not familiar with the use of graphs in physics and always had a hard time interpreting them herself (Interview 4).

Theme 2: The early career teachers' ePCK improved from their 1st year to their 2nd year, but it improved differently for in-field and OOF teachers.

The ePCK of most of the teachers improved by the 2nd year of teaching. The 1st year of teaching was certainly a challenge for all teachers, with important differences between the OOF and in-field teachers. By the 2nd year, however, all of the teachers improved in their ability to design lessons and draw upon useful instructional strategies. OOF teachers had fewer instances of teaching content in ways that misrepresented the concepts, while in-field teachers were better able to enact lessons that reflected their improved knowledge of student learning. In the following paragraphs, representative changes are shared among both the in-field and OOF teachers over the 2-year period.

In his 1st year of teaching, James showed limited ePCK in his OOF area of physical science. He reported being "kind of worried about physical science" (Interview 2) and identified the limited availability of time as a major concern when preparing to teach. He often used activities and lesson plans designed by other teachers to reduce the time he spent planning. When he enacted the lessons, he frequently struggled to answer student questions in the classroom. For example, while teaching a unit on atomic structure, he was unable to answer student queries about the splitting of atoms and atomic bombs (Observation 1_3). When asked to explain the underlying concepts associated with Newton's laws, he could not recall the basics. He specifically said, "I only remember parts of things, like parts of, like, Newton's Laws: action forces and reaction forces. I don't remember [any more of this topic]…" (Interview 2).

In his 2nd year of teaching, James was clearly familiar with the content and had more ideas about how to teach the content, which resulted in the improved design of his lessons. For instance, in one class, he designed a review that required students to answer questions by first working in groups of two and then participating in a whole-class discussion (Observation 2_1). By allowing students to work in small groups and then the larger group, students had an opportunity to clarify their ideas before the ideas were discussed in a large group. In helping students to learn the content better, he also created supports that were meant to foster student learning. One supporting mechanism involved creating a series of videos on forces and Newton's laws that students could view as needed (Interview 3). By his 2nd year, James realized that students learned differently and actively tried to provide new opportunities to support their learning. He started collecting supplementary reading materials, along with identifying appropriate demonstrations that represented the phenomena being studied.

Beth, an in-field teacher, showed improved ePCK in the 2nd year. In the 1st year, her depth of content knowledge was evident in her interactions with the students as she asked and answered questions. Her lack of ePCK was evident, as she did not consider student misconceptions and variations in student learning while planning instruction (Interview 2). For example, while measuring the velocity of a toy car, students manipulated the materials but did not complete the required written report. The 2nd year saw a marked change in her teaching, as she gave her students various opportunities to learn content. While studying a topic on static electricity, students performed an experiment, had a reading assignment, and then watched a video. They identified three things they had learned and stated a continuing question (Observation 2_3). Beth even referenced the standards to figure out the conceptual understanding students should have in this area.

These changes corresponded to the teachers' reports that their 2nd year of teaching was easier than the 1st. Their experience with the topics to be taught and their familiarity with the curriculum contributed significantly to their feelings of a better 2nd year. The exceptions to the reported 2nd-year ease were a result of being assigned extra classes to teach or a greater number of students in the classes. For instance, Mandisa, an OOF teacher, talked about her 2nd year being more difficult due to the increased class size (Interview 2).

Theme 3: The composition of ePCK fluctuated over time for most of the early career secondary science teachers but was still different between the in-field and OOF teachers.

Most early career teachers enhanced their ePCK from the beginning of their 1st year to the end of their 2nd year. However, in their 3rd year of teaching, many of the teachers revealed ePCK that resembled their 1st or 2nd year of teaching. The sustaining or rebounding nature of ePCK was unexpected and demonstrated uneven development of ePCK. Both in-field and OOF teachers demonstrated this 3rd-year variation, regardless of their in-field or OOF characterization. Again, this variation aligned with a return or early orientation, which differed between the OOF and in-field teachers. In the following paragraphs, representative examples highlight the ePCK fluctuation.

Barb, a mostly in-field chemistry teacher, revealed the fluctuating trend in her ePCK during her first 3 years of teaching. In her first 2 years, she frequently recognized the students' problems during instruction and used these observations to guide future lessons (Interview 2). Sometimes she deliberately planned her lessons to ensure students confronted their emerging knowledge, and other times she asked students questions about what they were learning during an investigation (Observation 2_3). This approach was evident in a lesson that had students find a relationship between the water displaced and the buoyant force acting upon an object (Observation 2_4). In this lesson, the students generated data and made an explanation about the observed phenomena. As the students considered all of their data, they challenged their misconceptions about floating and sinking objects. However, in the 3rd year, Barb returned to more traditional forms of instruction. She reduced the number of investigations available to students and instead provided notes and worksheets (Observation 3_3, Interview 4). This change was evident in a lesson on Newton's laws, which Barb taught for the third time. In this lesson, the students completed a worksheet requiring answers from the in-class demonstration and lecture.

Marrie, a representative OOF teacher, demonstrated the same trend as the other teachers regarding her fluctuating ePCK. In her 1st-year physical science class, she spent a significant amount of her time managing her students as they worked on a periodic table assignment (Observation 1_1). Without a strong understanding of the organization of the periodic table, she created a worksheet that amounted to locating information about the elements. This left time for her students to engage in nonlearning activities. Her activities and laboratory work were highly structured during her first 2 years, which often involved step-by-step instructions during note-taking sessions and laboratory work (Observations 1_1 and 2_3). Her instructional approach corresponded to her views of student learning, as she repeatedly indicated that her "students learn best by direct instruction" (Interview 3). With the alignment of these two areas, she saw little reason to change.

In her 3rd year of teaching, as she continued to teach OOF, she developed an instructional approach that provided even more guidance to the students. She began reading electronic slideshow presentations to her students (Observation 3_4) and included more detailed directions for her students during their laboratory work and activities. Supplementing this instructional approach, she frequently used procedural questions, such as, "How much room temperature water did you add?" (Observation 3_2) and directed students to skip questions that involved contemplating their results. For Marrie, this form of instruction ensured that all of her students received the same type of instruction. In addition, it saved her some time.

Summary and Discussion

In this study, we were interested in understanding the impact of OOF teaching on the development of early-career secondary science teachers' ePCK in the area of physical science. In order to determine how OOF teaching impacted the development of science teachers' ePCK, we followed teachers who were in-field and OOF in the area of physical science in their first 3 years of teaching. Our results suggest three important points about the development of ePCK.

First, this study revealed that OOF teaching impacts the development of a teacher's ePCK in the physical sciences. Specifically, the OOF setting kept early career teachers from strengthening their ePCK over time, which pertained to the ways they represented science in their classrooms and how they interacted with students. In this study, the in-field science teachers created instructional environments that helped students see how science proceeds or the complexity of a science concept. OOF teachers, on the other hand, focused on facts or definitions associated with the instructional topic.

The OOF teachers' limited ePCK was likely due to their limited SMK and the time they spent in OOF settings. SMK is essential in the formation of PCK (e.g., Gess-Newsome 1999; Kind and Chan 2019; Park and Oliver 2008). Rich SMK has connections between topics, which are emphasized in ePCK and found in pPCK. A rich SMK helps teachers respond to students' emerging ideas (Alonzo, Kobarg, and Seidel 2012; Park and Oliver 2008). Likely, the OOF teachers did not have foundational connections within the disciplines they were teaching. These connections are likely in the reservoirs of pPCK. In the absence of these connections, OOF science teachers had a limited representation of the topics in their classes. For OOF teachers, the sum of the variations within their SMK and the duration of OOF teaching events impacted their ePCK.

Second, in-field and OOF teachers had fluctuating ePCK that signaled they were building their knowledge of student learning and instruction in their early years of teaching. Most in-field and OOF teachers revealed higher levels of ePCK in their 2nd year of teaching, with lower levels of ePCK in their 1st and 3rd years. This fluctuation demonstrates that newly hired teachers are just building their teaching knowledge. This finding is similar to other studies that have revealed changes in the general PCK of newly hired science teachers (e.g., Lee et al. 2007; Luft et al. 2011). More importantly, this fluctuation in PCK may be attributed to the different experiences of the teachers, as suggested by Kind and Chan (2019). For newly hired teachers, their ePCK is just forming and is the result of varying experiences with the content they are teaching in the context of the curriculum and their peers and students. Different experiences will impact the formation of ePCK. Over time, these experiences may not have such a significant impact. A reservoir of pPCK may help decrease but not eliminate the fluctuation of ePCK.

Third, the results of the study suggest that being OOF is important to recognize among newly hired teachers. The prevailing discourse about newly hired teachers suggests that all teachers generally learn to teach in the same way (Feiman-Nemser 2010). This view is supported by studies of newly hired teachers that show no significant difference in instruction between early career teachers with a strong physics background and those with a limited physics content knowledge (Angell, Ryder, and Scott 2005) or that the PCK does not change in the first years of teaching (Friedrichsen et al. 2009). In our study, an examination of ePCK revealed that being OOF mattered among newly hired teachers.

Implications and Questions for Further Research

OOF teaching is a complex phenomenon. Results of this study indicate that when newly hired teachers are OOF they do not build their ePCK at the same levels as their in-field peers. Newly hired OOF teachers are then disadvantaged in developing their ePCK in their early years of teaching. Teachers are impacted, as well as their students.

From this study, some actions can be taken by those who work with OOF teachers. Supporting newly hired OOF teachers in their instruction is essential. In addition to providing newly hired teachers with mentors, there is a need to consider how to especially support OOF teachers in their instructional assignments. Providing access to study groups or professional development programs that emphasize ePCK and pPCK has been shown to be valuable to OOF teachers (Carpendale and Hume 2019; Hanuscin et al. 2020). The configuration and duration of these programs and similar programs are certainly worth consideration and study.

Another action involves those who prepare teachers. These educators need to help preservice teachers build their pPCK and enhance the connections within their SMK to levels that can support their instruction during their first years of teaching. In science, this means that preservice teachers should experience the teaching of different disciplinary topics using reform-based approaches. For instance, preservice teachers should make explanations about energy in biological, chemical, or physical settings. This approach should help preservice teachers build their pPCK, which will impact their ePCK. Understanding how linkages are made within pPCK, which can influence ePCK, is ripe for study among educators.

The most important action, however, is to be aware of the consequence of teaching OOF among newly hired teachers. While OOF teaching is consequential to the wellbeing of newly hired teachers, it is also consequential to enhancing and expanding new teachers' knowledge and practice. Ultimately, the residual impact of OOF teaching may be difficult to mitigate beyond the formative first years of teaching. By studying the impact of OOF teaching, educators can understand how to better prepare and support teachers who are likely to be OOF.

Conflict of Interest

The authors have no financial interest or benefit that has arisen from the direct applications of this research.

Funding Details

This study was supported by National Science Foundation under Grant #1829626 and Grant #0550847. The findings, conclusions, or opinions herein represent the views of the authors and do not necessarily represent the view of personnel affiliated with the National Science Foundation.

References

Alonzo, Alicia C., Mareike Kobarg, and Tina Seidel. 2012. "Pedagogical Content Knowledge as Reflected in Teacher–Student Interactions: Analysis of Two Video Cases." *Journal of Research in Science Teaching* 49(10): 1211-1239. doi:10.1002/tea.21055.

Angell, Carl, Jim Ryder, and Phil Scott. 2005. "Becoming an Expert Teacher: Novice Physics Teachers' Development of Conceptual and Pedagogical Knowledge." *Working Document.*

Azigwe, J. B., Leonidas Kyriakides, Anastasia Panayiotou, and Bert PM Creemers. 2016. "The Impact of Effective Teaching Characteristics in Promoting Student Achievement in Ghana." *International Journal of Educational Development* 51: 51-61. doi:10.1016/j.ijedudev.2016.07.004.

Baldi, Stephane, Catharine Warner-Griffin, and Chrystine Tadler. 2015. "Education and Certification Qualifications of Public Middle Grades Teachers of Selected Subjects: Evidence from the 2011-12 Schools and Staffing Survey. NCES 2015-815." *National Center for Education Statistics*.

Berry, Barnett, Alesha Daughtrey, and Alan Wieder. 2009. "Teaching Effectiveness and the Conditions that Matter Most in High-Needs Schools: A Policy Brief." *Center for Teaching Quality*.

Bogdan, Robert, and Sari Knopp Biklen. 2003. *Qualitative Research for Education: An Introduction to Theory and Methods*. Allyn and Bacon. Boston.

Carlson, Janet, Kirsten R. Daehler, Alicia C. Alonzo, Erik Barendsen, Amanda Berry, Andreas Borowski, Jared Carpendale et al. 2019. "The refined consensus model of pedagogical content knowledge in science education." In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science*, pp. 77-94. Springer, Singapore.

Carpendale, Jared, and Anne Hume. 2019. "Investigating Practising Science Teachers' pPCK and ePCK Development as a Result of Collaborative CoRe Design." In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science*, edited by Anne Hume, Rebecca Cooper, and Andreas Borowski, 223-250. Springer, Singapore.

Chan, Kennedy Kam Ho, Marissa Rollnick, and Julie Gess-Newsome. 2019. "A Grand Rubric for Measuring Science Teachers' Pedagogical Content Knowledge." In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science*, edited by Anne Hume, Rebecca Cooper, and Andreas Borowski, 251-269. Springer, Singapore.

Chu, Jessica Hsiaochieh, Prashant Loyalka, James Chu, Qinghe Qu, Yaojiang Shi, and Guirong Li. 2015. "The Impact of Teacher Credentials on Student Achievement in China." *China Economic Review* 36: 14-24. doi:10.1016/j.chieco.2015.08.006.

Clarke, Victoria, and Virginia Braun. 2017. "Thematic Analysis." *The Journal of Positive Psychology* 12(3): 297-298. doi:10.1080/17439760.2016.1262613.

Cochran, Kathryn F., James A. DeRuiter, and Richard A. King. 1993. "Pedagogical Content Knowing: An Integrative Model for Teacher Preparation." *Journal of Teacher Education* 44(4): 263-272. doi:10.1177/0022487193044004004.

Coetzee, Coréne, Marissa Rollnick, and Estelle Gaigher. 2020. "Teaching Electromagnetism for the First Time: A Case Study of Pre-service Science Teachers' Enacted Pedagogical Content Knowledge." Research in Science Education: 1-22. doi:10.1007/s11165-020-09948-4.

Darling-Hammond, Linda. 2000. "Teacher Quality and Student Achievement." *Education Policy Analysis* Archives 8: 1. doi:10.14507/epaa.v8n1.2000.

Dee, Thomas S., and Sarah R. Cohodes. 2008. "Out-of-Field Teachers and Student Achievement: Evidence from Matched-Pairs Comparisons." *Public Finance Review* 36(1): 7-32. doi:10.1177/1091142106289330.

Du Plessis, Anna E. 2015. "Effective Education: Conceptualising the Meaning of Out-of-Field Teaching Practices for Teachers, Teacher Quality and School Leaders." *International Journal of Educational Research* 72: 89-102. doi:10.1016/j.ijer.2015.05.005.

Du Plessis, Anna E., Annemaree Carroll, and Robyn M. Gillies. 2015. "Understanding the Lived Experiences of Novice Out-of-Field Teachers in Relation to School Leadership Practices." *Asia-Pacific Journal of Teacher Education* 43(1): 4-21. doi:10.1080/1359866X.2014.937393.

Du Plessis, Anna E., Annemaree Carroll, and Robyn M. Gillies. 2017. "The Meaning of Out-of-Field Teaching for Educational Leadership." *International Journal of Leadership in Education* 20(1): 87-112. doi:10.1080/1359866X.2014.937393.

Feiman-Nemser, Sharon. 2010. "Multiple Meanings of New Teacher Induction." In *Past, Present and Future Research on Teacher Induction: An Anthology for Researcher, Policy Makers and Practitioners,* edited by Jian Wang, Sandra J. Odell and Renee T. Clift, 15-30. Rowman and Littlehead, Lanham.

Fitchett, Paul Graven, Christopher J. McCarthy, Richard G. Lambert, Maytal Eyal, Emily C. Playfair, and Jendayi B. Dillard. 2019. "Examining Teacher Stress-Vulnerability in the US Secondary School Context." *Educational Review*: 1-24. doi:10.1080/00131911.2019.1619521.

Friedrichsen, Patricia J, Sandra K. Abell, Enrique M. Pareja, Patrick L. Brown, Deanna M. Lankford, and Mark J. Volkmann. 2009. "Does Teaching Experience Matter? Examining Biology Teachers' Prior Knowledge for Teaching in an Alternative Certification Program." *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching* 46 (4): 357-383. doi:10.1002/tea.20283.

Gess-Newsome, Julie. 1999. "Pedagogical Content Knowledge: An Introduction and Orientation." In *Examining Pedagogical Content Knowledge*, edited by Julie Gess-Newsome and Norman G. Lederman, 3-17. Springer, Dordrecht.

Grossman, Pamela Lynn. 1990. *The Making of a Teacher: Teacher Knowledge and Teacher Education*. Teachers College Press, Teachers College, Columbia University.

Hanuscin, Deborah L., Zandra de Araujo, Dante Cisterna, Kelsey Lipsitz, and Delinda van Garderen. 2020. "The Re-Novicing of Elementary Teachers in Science? Grade Level Reassignment and Teacher PCK." *Journal of Science Teacher Education* 31(7): 780-801. doi:10.1080/1046560X.2020.1778845.

Hashweh, Maher Z. 1987. "Effects of Subject-Matter Knowledge in the Teaching of Biology and Physics." *Teaching and Teacher Education* 3(2): 109-120. doi:10.1016/0742-051X(87)90012-6.

Hobbs, Linda. 2013. "Teaching ‘Out-of-Field’ as a Boundary-Crossing Event: Factors Shaping Teacher Identity." *International Journal of Science and Mathematics Education* 11(2): 271-297. doi:10.1007/s10763-012-9333-4.

Ingersoll, Richard M. 1998. "The Problem of Out-of-Field Teaching." *The Phi Delta Kappan* 79(10): 773-776. Retrieved from https://www.jstor.org/stable/20439339

Jerald, Craig D, and Richard Ingersoll. 2002. "All Talk No Action: Putting an End to Out-of-Field Teaching." Education Trust, Washington, DC.

Kind, Vanessa, and Kennedy K. H. Chan. 2019. "Resolving the Amalgam: Connecting Pedagogical Content Knowledge, Content Knowledge and Pedagogical Knowledge." *International Journal of Science Education* 41(7): 964-978. doi:10.1080/09500693.2019.1584931.

Lee, Eunmi, Michelle N. Brown, Julie A. Luft, and Gillian H. Roehrig. 2007. "Assessing Beginning Secondary Science Teachers' PCK: Pilot Year Results." *School Science and Mathematics* 107(2): 52-60. doi:10.1111/j.1949-8594.2007.tb17768.x.

Loughran, John, Pamela Mulhall, and Amanda Berry. 2008. "Exploring Pedagogical Content Knowledge in Science Teacher Education." *International Journal of Science Education* 30(10): 1301-1320. doi:10.1080/09500690802187009.

Luft, Julie A., Shannon L. Dubois, Ryan S. Nixon, and Benjamin K. Campbell. 2015. "Supporting newly hired teachers of science: Attaining teacher professional standards." *Studies in Science Education* 51(1): 1-48. doi:10.1080/03057267.2014.980559.

Luft, Julie A, Jonah B. Firestone, Sissy S. Wong, Ira Ortega, Krista Adams, and EunJin Bang. 2011. "Beginning Secondary Science Teacher Induction: A Two-Year Mixed Methods Study." *Journal of Research in Science Teaching* 48(10): 1199-1224. doi:10.1002/tea.20444.

Magnusson, Shirley, Joseph Krajcik, and Hilda Borko. 1999. "Nature, Sources, and Development of Pedagogical Content Knowledge for Science Teaching." In *Examining Pedagogical Content Knowledge*, edited by Julie Gess-Newsome and Norman G. Lederman, 95-132. Springer, Dordrecht.

Marks, Rick. 1990. "Pedagogical Content Knowledge: From a Mathematical Case to a Modified Conception." *Journal of Teacher Education* 41(3): 3-11. doi:10.1177/002248719004100302.

Mazibe, Ernest N., Corene Coetzee, and Estelle Gaigher. 2020. "A Comparison Between Reported and Enacted Pedagogical Content Knowledge (PCK) About Graphs of Motion." *Research in Science Education* 50(3): 941-964. doi:10.1007/s11165-018-9718-7.

Merriam, Sharan B., and Sharan B. Merriam. 2009. *Qualitative Research: A Guide to Design and Implementation*. The Jossey-Bass Higher and Adult Education Series. Jossey-Bass.

Miles, Matthew B., A. M. Huberman, and Johnny Saldaña. 2020. *Qualitative Data Analysis: A Methods Sourcebook.* SAGE, Los Angeles.

Monte-Sano, Chauncey, and Christopher Budano. 2013. "Developing and Enacting Pedagogical Content Knowledge for Teaching History: An Exploration of Two Novice Teachers' Growth Over Three Years." *Journal of the Learning Sciences* 22(2): 171-211. doi:10.1080/10508406.2012.742016.

Napier, Jessica B., Julie A. Luft, and Harleen Singh. 2020. "In the Classrooms of Newly Hired Secondary Science Teachers: The Consequences of Teaching In-Field or Out-of-Field." *Journal of Science Teacher Education* 31(7): 802-820. doi:10.1080/1046560X.2020.1800195.

National Research Council (NRC) (1996). *National science education standards [NSES*]. Washington DC: National Academy Press. doi:10.17226/4962.

National Research Council (NRC) (2000). *Inquiry and the national science education standards: A guide for teaching and learning.* Washington DC: National Academies Press. doi:10.17226/9596.

NGSS Lead States (2013). *Next generation science standards: For states, by states* [NGSS]. Washington, DC: National Academies Press. doi:10.17226/18290.

Park, Soonhye, and J. S. Oliver. 2008. "Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals." *Research in Science Education* 38(3): 261-284. doi:10.1007/s11165-007-9049-6.

Park, Soonhye. 2019. "Reconciliation Between the Refined Consensus Model of PCK and Extant PCK Models for Advancing PCK Research in Science. "In *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science*, edited by Anne Hume, Rebecca Cooper, and Andreas Borowski, 117-128. Springer, Singapore.

Rahman, Taslima, Mary Ann Fox, Sakiko Ikoma, and Lucinda Gray. 2017."Certification Status and Experience of US Public School Teachers: Variations Across Student Subgroups. NCES 2017-056." *National Center for Education Statistics.* Washington, DC.

Rosenholtz, Susan J. 1989. "Workplace Conditions that Affect Teacher Quality and Commitment: Implications for Teacher Induction Programs. "*The Elementary School Journal* 89(4): 421-439. https://doi.org/10.1086/461584.

Saldaña, Johnny. 2015. *The Coding Manual for Qualitative Researchers*. Sage. Los Angeles.

Sanders, Linda R., Hilda Borko, and J. David Lockard. 1993. "Secondary Science Teachers' Knowledge Base When Teaching Science Courses in and out of their Area of Certification. "*Journal of Research in Science Teaching"* 30(7): 723-736. doi:10.1002/tea.3660300710.

Sharplin, Elaine Denise. 2014. "Reconceptualising Out-of-Field Teaching: Experiences of Rural Teachers in Western Australia." *Educational Research* 56(1): 97-110. doi:10.1080/00131881.2013.874160.

Shulman, Lee S. 1986. "Those Who Understand: Knowledge Growth in Teaching." *Educational Researcher* 15(2): 4-14. doi:10.2307/1175860.

Shulman, Lee. 1987. "Knowledge and Teaching: Foundations of the New Reform." *Harvard Educational Review* 57(1):1-23. doi:10.17763/haer.57.1.j463w79r56455411.

Steyn, G. M., and E. Du Plessis. 2007. "The Implications of The Out-of-Field Phenomenon for Effective Teaching, Quality Education and School Management." *Africa Education Review* 4(2): 144-158. doi:10.1080/18146620701652754.

Wayne, Andrew J., and Peter Youngs. 2003. "Teacher Characteristics and Student Achievement Gains: A Review." *Review of Educational Research* 73(1): 89-122. doi:10.3102/00346543073001089.

Zepeda, Sally J., and R. Stewart Mayers. 2001. "New Kids on the Block Schedule: Beginning Teachers Face Challenges." *The High School Journal* 84(4): 1-11.

doi:10.1353/hsj.2001.0014

CHAPTER 3

EXPERIENCES OF SCHOOL SCIENCE COORDINATORS WHILE SUPPORTING TEACHERS DURING THE COVID-19 PANDEMIC: AN INTERNATIONAL STUDY

Singh, H., Luft, J.A., Tran, H., Ozen-Tasdemir, H., Huang, Y., and Whitworth, B. To be submitted to *International Journal of Science Education*

Abstract

This qualitative study explores the meaningful experiences of science coordinators from different parts of the world during the school closures due to the COVID-19 pandemic. In particular, it aims at understanding the shifts in knowledge, practices, and attributes of science coordinators and the resources they have drawn upon that have helped support science teachers during this time. The participants of this study were 15 science coordinators from 10 countries, including Canada, Chile, Mainland China, India, Kenya, Pakistan, Turkey, Taiwan, United States, and Vietnam. This study uses the concepts of organizational resources and capital as the framework to understand the experiences of school science coordinators. Data for the study were collected in the form of semi-structured interviews. Interviews were analyzed thematically using two cycles of inductive coding. Findings from the study indicate an increase in knowledge, practices, and attributes of technology (was required for the shift), collaboration, creativity, and interpersonal skills. The majority of the practices and attributes that were important during the pandemic were related to working with people (soft skills). SCs' knowledge, practices, and attributes translated as supports in the form of social and material resources available to the teachers. Implications of the study are discussed.
INDEX WORDS: Resources, knowledge, practices, attributes, science coordinators, international

Introduction

Science coordinators play an essential role in supporting and improving science teachers' delivery of high quality instruction (Tracy, 1996; Whitworth & Chiu, 2015), consequently influencing student achievement (Banilower et al., 2007; Desimone, 2009; Guskey, 2002). Science coordinators at the school and the district level influence teachers' instructional practices by providing subject-specific and day-to-day support and professional development (PD) for the teachers (Whitworth & Chiu, 2015). Their role became even more valuable during of the COVID-19 pandemic as they helped support science teachers in ensuring educational continuity through distance learning and bringing learning content from classrooms into students' homes (UNESCO, 2020).

As a part of the health measures undertaken by governments worldwide during the COVID-19 pandemic, K-12 to post-secondary schools have been physically closed. Administrators at schools had little time to prepare teachers for this unprecedented and swift transition to distance learning. The sudden shift in instruction from a well-structured school system to distance learning was challenging for many teachers. Teachers had little time to acquire and upgrade their information and communication technologies (ICT) skills, which involves understanding hardware, software applications, and information systems (Park et al., 2009).

The effectiveness of the new learning environment is influenced by the teachers' readiness and the availability of adequate infrastructure. Teachers' beliefs about the usefulness of technology and the perceived ease of use influenced their successful adoption of ICT (Tarhini et al., 2015). Teachers in some schools may be skilled in using computer-based technologies for teaching and learning, making the transition to online learning relatively easy. For other teachers, this may pose a difficult challenge (Buabeng-Andoh, 2012).

School leaders such as science coordinators have continued to lead and support science teachers remotely in the changed context of the pandemic, as they have been physically distanced from the teachers. Effective school leaders are responsive to the context of their work, as they understand and respond to the demands of their context (Leithwood et al., 2020). The pre-existing knowledge, practices, and attributes (KPA) of school leaders may not be adequately and fully suitable for supporting science teachers during the pandemic. We may see be a shift in the KPA of school coordinators necessary for their leadership roles.

This qualitative study explores the shift in the roles of science coordinators during the pandemic and the resources that are available to science teachers as an outcome of the coordinators' roles. The knowledge, practices, and attributes of science coordinators that have attributes they have developed during this time are investigated in this study. This study asks the following questions:

1. *How did the knowledge, practices and attributes of science coordinators over the world before and during the COVID-19 pandemic change as they worked to support teachers?*
2. *What resources did they draw upon in supporting their teachers? How did this impact their work?*

Framing of the study

This study uses the concepts of organizational resources and capital (Bourdieu, 1986; Gamoran et al., 2000; Spillane & Thompson, 1997) as the framework to understand the experiences of school science coordinators. The terms resources and capital have been used interchangeably in the literature. Resources are defined as the assets that teachers can draw on in the context of their classroom, school, or community, to improve their pedagogy and development (Lee et al., 2016). The three categories of resources we have considered essential for teachers are human, material, and social resources.

Human resources include teachers' knowledge that influences the quality of instruction. (Shulman, 1987) identified these as pedagogical knowledge (general strategies used for teaching), content knowledge (what teachers know about their subject), and pedagogical content knowledge (how to teach a particular subject matter to foster student understanding). Human resources shape the quality of teachers' instruction and student learning (Coleman, 1998). Social resources constitute a professional network of collegial relations among individuals, both within and outside an organization (Coleman, 1998). These include the norms of trust, collaboration, shared responsibility, collective decision-making, and common values. Coleman (1988) identifies social capital as a resource for action. Social capital can impact teachers' learning and development (Luft et al., 2015). Material resources include curriculum, textbooks, supplies, laboratory equipment, technology, time for planning, teaching, collaboration among teachers, and funding (Coleman, 1998).

Research suggests the interconnected nature of resources. Teachers can draw upon many resources simultaneously, and resources can be mutually supportive. Navy et al. (2020) found that interactions of resources in context can help support teachers. Teachers in a professional development program (social resource) perceived curricular materials (material resources) as a reduced barrier to teaching science (Lee et al., 2016). Social resources have improved teachers' access to human and material resources (Coleman, 1988; Lee et al., 2016; Rivera Maulucci, 2010). Science leaders' human capital developed through learning depends on the "development and exploitation of social capital." (Spillane & Thompson, 1997, p. 199). School leaders rich in human capital (leaders' knowledge, skills, and disposition) and social capital (social links, norms, and trust that support communication) will get richer in human capital, which can help teachers to teach effectively (Spillane & Thompson, 1997).

Review of literature

Knowledge, Practices, and Attributes

In the United States, district science coordinators (DSC) are responsible for supporting science teachers. Given that DSCs are science teacher leaders, the knowledge, practices, and attributes that they hold are important. In addition, DSCs' knowledge, practices, and attributes (KPA) help guide science teachers' personal growth (Watson et al., 2020). However, research on DSCs and science coordinators is limited. Existing research typically looks into the roles and responsibilities of DSCs (Lee et al., 2016; Whitworth et al., 2017). In the absence of rich literature on the KPA of DSCs, we have considered the KPA of school leaders to inform the study.

Personal knowledge is defined as the knowledge held by individuals that helps them to think and perform in practical situations (Eraut, 1997). Personal knowledge is acquired through propositional knowledge, i.e., the academic and factual knowledge that is subject to quality control by peer review and editors and codified and stored in publications, libraries, etc. It is constructed through personal experiences and reflection. For DSCs, the literature on the knowledge base essential for their work is thin. In a study of 20 DSCs, Watson et al. (2020) have investigated the knowledge, practices, and attributes that are foundational for the roles of DSCs. They found that DSCs perceived knowledge of science pedagogy and knowledge of facilitating professional learning as the most important in their work. Other knowledge bases identified by

Watson et al. (2020) as essential include knowledge of state and national standards, interpersonal knowledge, and knowledge of trends and research in science education. Some DSCs identified science content knowledge as essential for their work while others did not.

Leithwood and Jantzi (2008) identified the following four basic leadership practices for school leaders. (i) The first practice includes building a shared vision with colleagues fostering group goals, and demonstrating high-performance expectations. This practice helps motivate school leaders' colleagues. (ii) School leaders provide teachers with individualized support, foster intellectual stimulation, and model appropriate values and behaviors. This helps teachers build the requisite knowledge and skills to meet goals and the dispositions that help teachers persist in using the knowledge and skills. (iii) The third practice entails school leaders building a collaborative culture, restructuring the organization, building relationships with stakeholders such as parents and community and the wider environment. This creates work conditions that allow teachers to make the most of their motivation, commitment, and capacities. (iv) The fourth practice involves school leaders creating a productive learning environment for teachers by providing teaching support and monitoring school-based activities.

The practices mentioned above that are essential to the work of school leaders were found to be consistent when revisited and reviewed by Leithwood et al. (2020), suggesting the principles of good leadership are a constant. While looking at DSCs' practices, Watson et al. (2020) found that DSCs value communication with teachers and stakeholders, building relationships with teachers, and supporting teachers through professional learning opportunities the most. However, emerging research points to the importance of context in leadership practices. Harris (2020) suggests that COVID-19 has dramatically changed leadership practices. The contextual responsiveness of leadership implies a shift in the practices of school leaders during the pandemic (Harris, 2020). Context such as classroom and school environment, induction programs, and new curriculum have been found to influence teachers' learning and development (Bianchini, 2012; Henze et al., 2009; Luft et al., 2015; Timperley et al., 2008)

In leadership literature, attributes are defined as the inner personal qualities of an effective leader (Sperry, 2002). Mumford et al. (2000) suggest that leaders' attributes like their cognitive ability, motivation, and personality influence their knowledge and skills. On similar lines, Watson et al. (2020) observed that attributes of DSCs were often linked with their practices. DSCs' top valued attributes include approachability and student focus. Interpersonal attributes and practices were emphasized in the DSCs' day-to-day role (Watson et al., 2020). Goolamally and Ahmad (2014) identified five attributes that school leaders must possess to make a school excellent. These are integrity, forward-thinking, inspiration, competence, and self-efficacy. School leaders' attributes have been found to impact teachers' job satisfaction (Hartinah et al., 2020), student achievement Leithwood and Jantzi (2008) and school climate (Blatt, 2002).

Online teaching during the pandemic

Online education that schools engaged in during the pandemic required teachers to not only use ICT as a part of instruction but to shift the entire instruction online. This shift can be challenging as teachers are expected to implement change at short notice and under adverse circumstances (Dawes, 2001). Teaching in an exclusively online environment requires a different set of skills than face-to-face instruction. Teachers familiar with the use of ICT for instruction can struggle while teaching in a wholly online environment (World Bank, 2020). World Bank (2020) cautions that "transitioning to online learning at scale is a challenging and highly complex undertaking for education systems, even in the best of circumstances" (p. 2). It requires an instructional approach, pacing, interaction model, and assessment to be kept in mind to transfer instruction online.

Teachers need ample support while shifting their practice online. They need to be supported to address the students' academic needs and their social health, and social and emotional needs (OECD, 2021). Teachers need the support and training to develop appropriate skills, knowledge, and attitudes to use ICT in classroom instruction effectively and continuous PD to maintain these skills (Hennessy et al., 2005; Newhouse, 2002). Bozkurt and Sharma (2020) advocate building support communities that enable sharing of knowledge and experiences that provide meaningful learning for students and are grounded in the pedagogy of care. Trust and Whalen (2020) found that many educators relied on informal and self-directed learning. Lack of adequate training of teachers acts as a barrier to using ICT in teaching and learning (Özden, 2007; Toprakci, 2006). Teachers with training and preparation to use ICT for instruction have been shown to be more effective in its use than teachers who have not received the training (Winzenried et al., 2010). Teachers who have adequate ICT skills will likely design and facilitate quality instruction. For example, in school districts in New Hampshire, where an online backup system already existed due to school closure on snow days, the transition to online instruction was seamless (The Harvard Gazette, 2020).

The COVID-19 pandemic has unfolded new opportunities and challenges for teaching and learning in unchartered territory (Ferri et al., 2020). Online instruction during the pandemic has been referred to as a "great online experiment" (Zimmerman, 2020) and recognized as an opportunity to test online pedagogic approaches (Bozkurt & Sharma, 2020). Trust & Whalen (2020) used an online survey of 325 K-12 educators to identify the challenges they faced as instruction shifted online during the pandemic. Educators reported feeling overwhelmed and unprepared to use online teaching strategies or tools as they strived to alter their instruction to fit into the fluctuating situation. Other challenges include the unavailability of quality internet access (for students and educators) and a lack of knowledge about online teaching strategies, teaching tools, and communication tools.

Empirical studies on online teaching and learning during the pandemic published so far investigate the experiences of educators and students, inequities faced by learners, and the opportunities and challenges faced by teachers (Aguliera & Nightengale-Lee, 2020; Alvarez Jr, 2020; Ferri et al., 2020; Oliveira et al., 2021; Shim & Lee, 2020; Trust & Whalen, 2020). However, none of the studies have investigated the work of school leaders in terms of the KPA that helps support science teachers and the resources they draw upon while supporting teachers. Moreover, existing studies are based in the local context. Examining the work and experiences of science coordinators from different countries during the pandemic will provide opportunities to build new insights into supporting science teachers in the changed context of online teaching.

Methodology

This qualitative study explores the shift in the roles of school science coordinators worldwide and the resources they draw upon in supporting science teachers during the COVID-19 pandemic.

Participants

The study participants are science coordinators at the school or district level from ten countries, including Canada, Chile, Mainland China, India, Kenya, Pakistan, Turkey, United States, Taiwan, and Vietnam. One or two participants were selected from each country, making a total of 15 participants. The participants were selected based on their role of supporting school science teachers, not based on their job titles, which varied across countries. The term science coordinators (SCs) has been used to describe the participants, irrespective of the job title they hold in their respective school systems. The sampling of the participants was purposeful. Members of the research team contacted science coordinators from their native countries and their contacts in other countries. Including participants from different countries helped understand the phenomenon in question from a global perspective. A diverse group of participants helps understand the meaningful and significant experiences of the phenomenon (Creswell, 2008). For demographic information of participants, see Table 1.

Table 3.1

Demographics of participating science coordinators

SC	Country	Position	Type of school	Teaching duty	Format of instruction
Mike	Canada	STEM coordinator	Public	Yes	Online and face to face
Finn	Chile	Head of science teaching strategies	Private	Yes	Online
Kaira	India	Science department head	Private	Yes	Online
Rita	India	Science coordinator	Private	Yes	Online
Anna	Kenya	Science department head	Private	Yes	Hyflex
Xia	Mainland China	Research team leader	Public	Yes	Online
Ibrahim	Pakistan	Science coordinator	Private	Yes	Online
Idrees	Pakistan	Science coordinator	Private	Yes	Online
Yu-Lin	Taiwan	Science coordinator	Public	Yes	Face-to-face
Murat	Turkey	Science leader	Public	Yes	Online
Sedat	Turkey	Science leader	Public	Yes	Online
Cindy	USA	Science specialist	Public	No	Online
Grace	USA	Science instructional support specialist	Public	No	Online
May	Vietnam	Teacher leader	Public	Yes	Online
Nam	Vietnam	Teacher leader	Public	Yes	Online

Note: Hyflex instruction involves teaching in-person and online students simultaneously.

Data Collection

Data were collected in the form of semi-structured interviews (Seidman, 2013) and follow-up interviews if required. Interviews were held online using Zoom or Google Meet, as per the participating leaders' preference. Interviewers endeavored to create a relationship with the participants guided by respect and a genuine interest in understanding their experiences (Seidman, 2013). This contributes to the validity of the captured information (Kirk et al., 1986). The interviews consisted of two parts. The first part included demographic questions on the background and roles of the SCs. The second part focused on understanding their knowledge, practices, and experiences. SCs were asked about the knowledge and practices that are unique to being successful in their work supporting teachers, those that have been helpful during and after transitioning to distance learning, and their major takeaway during this time. The interviews occurred during school closures due to the COVID-19 pandemic between August 2020 and January 2021. Each interview lasted between 45 to 60 minutes.

Interviews were conducted by the researchers in the native language of the participants—this increased access to participants from non-English speaking countries. Interviewers had experienced the education system, culture, and language of the participants' countries as students and/or teachers. They were familiar with the local education context and languages spoken. Interviewers helped capture the overall meanings of the interviews and the subtle differences in meanings that exist due to cultural differences and nonequivalent words (Patton, 2014), and reduce bias and subjectivity in interpreting the interviews (Kapborg & Berterö, 2002).

Data Analysis

Data analysis started concurrently with data collection. Data was coded once right away on the collection and again after a few days. Two researchers coded each interview (first author and interviewer or another researcher). Researchers discussed their initial difficulties and disagreements till a common understanding of coding was developed. Once all interviews were coded, the team discussed the coding, bringing a shared vision to the coding.

We used two cycles of coding for data analysis. The first cycle of coding used structural coding (Miles, Huberman, & Saldana, 2020). We began with a list of primary a-priory codes based on the research question and what might appear in the data. For example, codes of knowledge before Covid-19, knowledge during Covid-19, practices before Covid-19, and practices during Covid-19 were based on the research question. Additional codes such as challenges faced, innovative strategies, and social support factors emerged as the data was analyzed. Subcodes were inductively created, and second-order tags were assigned after the primary codes. These codes emerged during the analysis and helped detail and enrich the primary codes (Miles & Huberman, 2020). This coding helped initial data categorization and examined it for commonalities, differences, and relationships (Saldaña, 2016).

For the second cycle of coding, a content analysis summary matrix was created to help arrange the coded data systematically in the same location and identify the findings (Miles et al., 2020). The matrix was framed with the SCs placed in columns and knowledge, practices, and attributes sub-codes placed in rows. Each cell of the matrix represented a particular knowledge or practice of an SC. For example, a cell for Xia represented her views and experiences about collaboration with and between teachers, issues faced concerning these, strategies used, and direct quotes. The data were analyzed iteratively to allow for careful comparison across participant narratives. A smaller number of themes emerged after careful analysis of the data.

Ensuring Validity and Reliability in the Study

The study's design and practices followed by the research team contributed to quality data collection and analysis. Triangulation occurred by involving multiple researchers in data collection and analysis (Miles et al., 2020). Triangulation by researcher contributed to the validity of the study. Using different researchers for data collection and analysis helped improve the consistency of the data collected and the trustworthiness of the analysis (Patton, 2014). Team coding added reliability to the findings (Merriam, 2009; Miles, Huberman, & Saldaña, 2020).

Findings

The findings below are presented in response to each question.

RQ1. Knowledge, Practices, and Attributes Central to the Work of SCs During the Pandemic

The first question asks about the shift in the SC' knowledge, practices, and attributes as they worked supporting teachers. The shift is summarized in table 3.2. Most notable during this time is an increase in technology (was required for the shift), collaboration, creativity and interpersonal skills. The majority of the practices and attributes that were important during the pandemic were related to working with people (soft skills).

We saw knowledge of technology and practice of using technology for collaboration and communication as the focus of SCs work during the pandemic. The use of technology included managing SCs' work, helping teachers use technology for instruction and assessment, and thinking about using technology to create opportunities for students to interact with science. SCs developed their knowledge of meaningful use of technology for designing, implementing, and assessing instruction and practices such as communication and collaboration. Some SCs learned to use technology for instruction and training their teachers, while others trained along with their teachers. For example, Yu-Lin and her teachers trained to use technology to prepare schools to shift to distance learning, even though eventually, schools in Taiwan did not close down. Grace provided training focused on flipped learning and blended learning to maximize the quality of synchronous teaching and learning.

Table 3.2

Knowledge, practices, and attributes identified by science coordinators and evident in their work before and during the COVID-19 pandemic

		Pre-COVID-19	During COVID-19
Knowledge	Technology	-	X
	Pedagogy	X	X
	Assessment	X	X
	Trends in science education	X	X
	Content	X	-
Practices	Technology	-	X
	Collaboration	-	X
	Communication	X	X
	Facilitating professional learning	X	X
Attributes	Creativity	-	X
	Interpersonal	-	X

Note: X represents the presence of a Knowledge, Practice, or Attribute. The highlighted Knowledge, Practices, and Attributes indicate a shift during the pandemic.

SCs and their teachers' previous experiences with using ICT proved to be valuable during the pandemic. For example, serendipitously, just before the pandemic, Grace had been through intensive facilitator training on using ICT to turn a typical classroom into a virtual learning opportunity. She felt that this helped her immensely in supporting teachers in her school district to transition to online instruction during the pandemic. Mike had a master's degree in educational technology, a thorough knowledge of the affordances that technologies offer, and knowledge of using technology for transformative practices rather than simply a substitute for old teaching practices. May and Nam encouraged their teachers to use ICT for instruction pre-pandemic. May's teachers’ familiarity with the flipped classroom model was helpful during the pandemic. In Chile, Finn's teachers had experienced integrating technology for instruction due to a recent social crisis that led to schools' physical closure. Murat's teachers had been using simulations for laboratory work, which proved helpful during the pandemic. SCs acknowledged prior experiences with technology as advantageous during the pandemic. On the other hand, Sedat felt that if his school had better access to technology infrastructure, shifting to the online format would have been easier.

Moving forward, all the SCs recognized that the use of technology in teaching and learning was here to stay beyond the pandemic and that instruction post-pandemic would not be the same as before. Mike felt that the pandemic has "hit fast-forward" in teachers adopting new technologies for teaching. He said that:

> "It (pandemic) has compelled teachers who have been resistant in adopting technology for instruction to overcome the inertia that prevents them from using new technologies and teaching practices.........When I see teachers struggling with teaching during the pandemic, the one thing that comes to my mind is that reaching students in a way that the media you are communicating with does not become a barrier to learning".

Rita believed that the experiences with technology could reduce teachers' work and planned to use it beyond the pandemic. Izhar underscored online instruction and technology as need of the hour and was waiting to happen. He saw this as a great learning experience for him and his teachers that has helped catapult them into a new digital future.

Practices of communication and collaboration were at the core of SCs' work during the pandemic. SCs stressed the importance of collaboration and teamwork with the science teachers and between the science teachers. These practices helped SCs valuing teachers' ideas and giving them a voice (Finn, Sedat, Rita, Anna). Working with teachers helped them "pool their cognitive resources" (Finn). SCs affirmed that teacher-to-teacher feedback and advice from colleagues helped teachers refine their teaching materials like video lessons and teaching practices (May, Xia, Kaira, Rita). Xia described her job as a research team leader as a "centripetal force" that brings the teachers together. Communicating with students, teachers, and parents during the pandemic also emerged as an essential practice for the SCs. SCs relied heavily on feedback from teachers, student's families, and acquaintances. For example, while designing sample video lessons for her teachers, Cindy tried out science activities with her neighbor's children to see if they worked as expected "before putting them out there."

SCs' creativity and interpersonal attributes were evident in their work. These included thinking about ways for students to interact with science in non-traditional ways. Rita, Kaira, and Cindy guided their teachers to design activities that students could perform at home, with readily available material, while giving options for materials that could be used. For example, students could investigate variations in friction with different types of floors and surfaces at home. Rita worked with her teachers to create new opportunities for the students to do science using online platforms. These included students working on an online science magazine started at the time, hosting an online science quiz, and an online talk show on a solar eclipse that was taking place at the time. Anna and her teachers brainstormed ideas for students to collect data for their yearly science project. Students were given the options for collection of data. They could perform activities at home and video graph or photograph them, use online simulations to collect data, or come in one at a time to work in the school laboratory. SCs' work with teachers during the pandemic reflected their interpersonal attribute.

RQ2. Support in the Form of Resources Available to Teachers

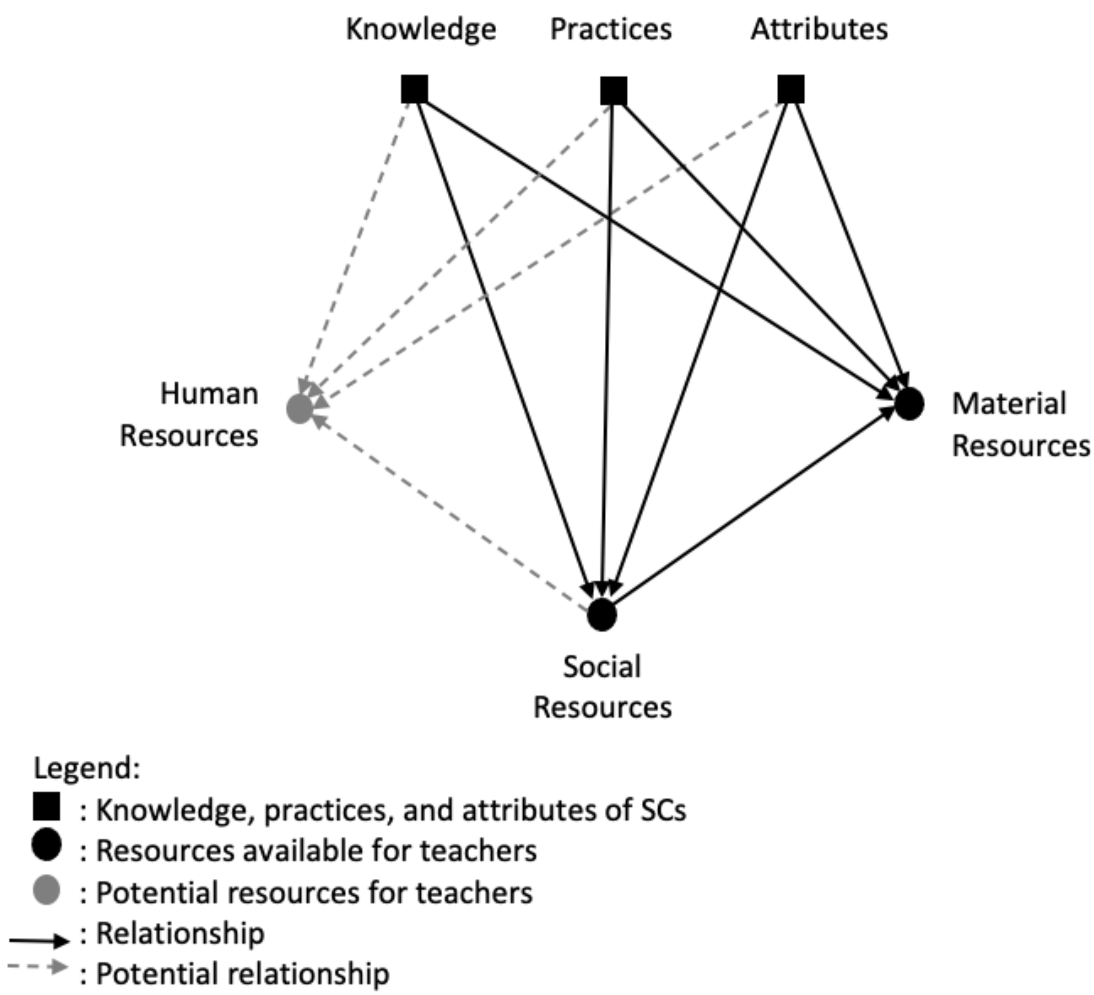
The second question is about the resources that were available to the SCs to support the teachers. The results are presents in Figure 1. Material and social resources were the most important resources during the pandemic. The KPA of SCs were a source of social and material resources. Social resources were in turn a source of material resources.

SCs' KPA translated as supports in the form of resources that were available to the teachers. These resources were social and material resources. Practices of communication and collaboration resulted in social resources for teachers. Kaira defined her role during the pandemic as more supportive and collaborative than before. Xia said, "I bring everyone together to discuss, to improve each teacher." Rita recognized that her "teachers are very innovative. They give me suggestions in so many ways, how to do things.......It is a team effort where we collaborate with ideas". She encouraged different subject area teachers to pool their resources and work together. For e.g., science and English language teachers combined some English and science lessons, and co-taught them. Rita felt that this would reduce the stress and workload of teachers and students.

Communicating with students, teachers, and parents during the pandemic also emerged as an essential social resource for the SCs (Rita, Ibrahim, Finn, Xia, Kaira, Nam, Yu-Lin, Murat). Rita reiterated that she was available 24x7 for her teachers, which was different from the pre-pandemic days when she met with them weekly. SCs relied heavily on feedback to complete the loop of information. This included giving feedback to the teachers and eliciting feedback from stakeholders, family, and acquaintances. For example, while designing sample video lessons for her teachers, Cindy sought feedback on activities she designed from her neighbor's children. Kaira's daughter refused to attend classes where instruction centered around the teacher talking at the students and showing videos and "had nothing new to offer." This made Kaira think of ways to make science instruction "pedagogically sound" and more "interactive and exciting." Staying connected with the parents and students helped the SCs understand the problems the students faced. For example, Kaira and her school management elicited critical feedback from parents on the effectiveness of the system they had put in place. They used Google forms to get feedback from parents about any issues they faced regarding access to online classes, the student's learning experiences, and issues like stress and screen time that students may face.

Figure 3.1

Resources available to SCs in supporting science teachers



SCs recognition of teachers' struggles in the changed context provided the teachers with social support. For example, Anna's school followed the hyflex format of instruction wherein the teachers taught in-person and online students at the same time. Anna recognized this as pedagogically challenging for the teachers. Teachers planned and implemented laboratory work, activities, and group work in a hyflex environment with little formal training. She acknowledged that the teachers were doing their best in the circumstances, and it was essential to encourage and appreciate them. Grace, Finn, Anna, and Kaira talked about their teachers feeling exposed and vulnerable in the online teaching environment. In recognition of teachers working very hard and trying their best, they thought it imperative to exercise patience with the teachers and provide them with encouragement and support.

Material resources for teachers resulted from SCs making these directly available to the teachers, or teachers working collaboratively to create material resources. Material resources directly provided to teachers included learning management systems for conducting online classes (e.g., Google classroom), online teaching resources like applications and websites, digital reading materials, online assessment applications (e.g., Nearpod), creating authentic online assessment the answers to which cannot be googled (e.g., apply the principles of traffic control to a particular neighborhood). Other material resources were created by the teachers through the practices of collaboration and communication, while integrating the knowledge of technology, and attributes of creativity and interpersonal. For example, Rita collaborated with her teachers to create revised timetables, create assessment plans, and revise the curriculum. Her teachers created demonstration lessons which she and her team of science teachers observed and provided feedback on. SCs affirmed that teacher-to-teacher feedback and advice from colleagues helped teachers refine their teaching materials like video lessons and teaching practices (May, Xia, Kaira, Rita).

Discussion

This study askes two questions, and these will be answered in this discussion. The first question is:

How did the knowledge, practices and attributes of science coordinators over the world before and during the COVID-19 pandemic change as they worked to support teachers?

Through this qualitative interview study, we have attempted to understand international SCs' experiences and listen to their voices, and do not endeavor to make any generalizations. We understand that contextual factors like physical access to up to date computers and high-speed internet, and non-material resources like prior experiences with technology, user's skills, type of device used, availability of educational content in regional languages, etc. can impact the quality of users' experiences with online education (Hargittai & Hsieh, 2013). These factors varied across countries. Consequently, the challenges and experiences of the SCs differed. Other contextual factors include unscheduled power outages, internet connectivity in rural and remote areas, access to and adequacy of technology devices by teachers and students, financial difficulties faced by schools due to parents' inability to pay school fees, student attendance, access to textbooks and educational materials, and copyright laws affecting sharing of digital resources. Despite these variations in context, an emphasis on some KPAs emerged from the data analysis.

The knowledge of technology, practices of using technology for collaboration and communication, and creativity and interpersonal attributes were identified by SCs as valuable during the pandemic. The use of technology for instruction during the pandemic was a necessity rather than a choice. We saw ICT at the center of SCs' work with teachers and interactions with teachers and stakeholders. Prior experiences of SCs' teachers with technology proved advantageous during the pandemic. Similar observations are made by the World Bank (2020). SCs also anticipated technology as a significant player in post-pandemic teaching and learning. Communication and collaboration with parents and teachers and teamwork were significant practices that helped SCs shift instruction to the online environment. Effective communication and coordination with stakeholders within and outside the school are effective in building consensus and trust (UNESCO, 2020). Collaborations with colleagues are considered an important form of professional development for teachers (Vangrieken et al., 2017) and positively impact student achievement (Pil & Leana, 2009; Shea et al., 2018). The knowledge and practices identified by SCs in the study align with those identified by Watson et al. (2020), with the addition of knowledge of technology at the time of the pandemic.

The emphasis on certain KPAs of SCs reflect the changed needs of science teachers during the pandemic. The sudden shift in the context of instruction from a well-structured school system to distance learning influenced the areas of instruction that teachers needed support with. The immediate and unforeseen shift gave teachers little time to acquire and upgrade their ICT skills. When this shift to online instruction is sudden and unexpected, it can be challenging for many teachers (Dawes, 2001). Traditionally, online distance education is a learning process that provides agency, responsibility, flexibility, and choice to the learners. It provides the learners with an alternative and flexible option for learning (Bozkurt & Sharma, 2020). What teachers engaged in during the pandemic was a temporary solution to an emergency situation, calling for a different set of strategies and priorities (Bozkurt & Sharma, 2020). Consequently, we saw a shift in the roles of SCs as they accommodated the needs of the science teachers.

With the sudden shift to the distance learning format, reform-based science practices could be the first victim. At such a time, teachers' focus would shift to adopting a different mode of instruction and dealing with other prominent issues such as students' access to distance learning, equity, and stress. The initial PD for teachers focused on helping them become familiar with technology for instruction, motivate students to attend online classes, stay in touch with the students, and provide the students with social and emotional support. This is in line with the recommendations of the OECD (2021). When it became clear that the pandemic teaching and learning conditions would stay longer than anticipated, SCs started thinking of instruction that focused on students gaining conceptual knowledge, critical thinking skills and assessing student learning. This was the focus of the later PD. Similar preliminary findings have been reported by a (NextGenScience, 2020) study, which reports lesser student engagement and instruction emphasizing whole class meetings and independent work during school closure due to the COVID-19 pandemic. Sophisticated pedagogical practices where students are engaged in learner-centered and project-based strategies may not be easily transferred to a wholly online environment (World Bank, 2020).

The second question of the study is:

What resources did they draw upon in supporting their teachers? How did this impact their work?

This study reveals that the SCs drew upon social and material resources to support science teachers. The KPA important to SCs during the pandemic involved working with people. This points to the importance of building interpersonal attributes in school leaders and teachers. SCs’ KPA translated as social and material resources, and likely their human resources. Between these resources, social resources emerged as the most important in supporting science teachers to teach online during the pandemic. Social resources, in turn, provided opportunities for teachers to interact with colleagues and work collaboratively to discuss their work, generate material resources, share expertise, and build their knowledge of teaching and learning in the online environment (material and human resources). Teachers could build their pedagogical knowledge, pedagogical content knowledge, technological pedagogical content knowledge, and knowledge of reform-based instructional practices through the process. However, teachers may actively access these resources, or the resources may be latent if not perceived as valuable by teachers (Navy et al., 2020).

This study extends findings from prior research. Previous research has recognized the importance of social resources like PD, mentors, and colleagues, human resources of teacher knowledge, and material resources like curriculum and laboratory materials in improving teachers' classroom instruction and experiences (Desimone et al., 2002; Grossman & Thompson, 2008; Hirsh, 2001; National Research Council, 2006; Rivera Maulucci, 2010; Yoon et al., 2017). Research also indicates the interconnected nature of these resources, as was observed in this study (Coleman, 1998; Spillane & Thompson, 1997). However, scholars have studied these resources for teachers in isolation. Thinking of resources in combination with the KPA of school leaders provides new insight into better supporting science teachers in an online environment. The supports available to science teachers during the pandemic are especially critical as teachers transitioned to the online environment without adequate preparation. The KPA of school leaders and the associated resources identified in this study will help support teachers in technology-rich post-pandemic teaching and learning.

School leadership has been recognized as equally important as knowledge of pedagogy and technology during the pandemic (Burgos et al., 2021). This study also emphasizes the role of school leaders (e.g., DSCs) in supporting science teachers. During the pandemic, school leaders supported science teachers in a novel context with which they themselves may have been unfamiliar. As Harris and Jones (2020) point out, "School leaders are walking a tightrope without a safety net. There are no precedents and no guides to leading schools in a pandemic" (p. 244). This study points to the need to prepare and support school leaders through PD programs specially designed for them. In the United States, DSCs have the role of supporting science teachers in their school district. However, little is known about PD opportunities for DSCs and their impact on teachers' classroom instruction (Kennedy, 2016). Findings from the study also suggest that PD focused on building interpersonal practices like collaboration and communication, and using technology for instruction can help teachers access social and material resources and have an opportunity to build their human resources.

Context has been recognized as important in research related to teacher's learning and knowledge development (Bianchini, 2012; Henze et al., 2009; Luft et al., 2015; Shulman, 1987; Timperley et al., 2008). Teachers are prepared and supported to teach in a particular context—for example, a particular subject, grade level, or instruction format. A sudden change in the teaching context without the appropriate preparation can result in teachers unprepared to deliver high-quality instruction in the new context. One such situation was experienced during the pandemic when schools shifted to the online format without adequate teacher preparation. These teachers may be knowledgeable about the content, pedagogy, and reform-based teaching practices. However, they may not have the knowledge and experience of teaching science in a completely online format. Such a situation may result in the teachers being out-of-field in context (OOF_C). OOF_C teachers may have experiences similar to those of out-of-field teachers who teach outside their subject area expertise. We know that out-of-field science teachers struggle in developing their knowledge for teaching and use low-level science instruction practices (Napier et al., 2020; Singh et al., 2021). In such a scenario, the role of science leaders in supporting science teachers is paramount.

Implications

The findings of this study are significant due to several reasons. Firstly, teaching and learning during the COVID-19 pandemic are unprecedented, unique, and recent. Thus, there is minimal research on how the shift in instruction has influenced teaching and learning, particularly school leaders' experiences. Moreover, little research exists on education systems moving to distance learning on such short notice and at a large scale as has been experienced during the pandemic. This study attempts to fill this void by exploring the work of school science leaders supporting science teachers during the pandemic. Tapping into the collective experiences of international participation offers an opportunity to gain a global rather than a localized insight into dealing with the current and future crisis.

Secondly, education in the post-pandemic world may not be the same as before, potentially making the pandemic a turning point in education systems worldwide. Schools and teachers have experienced new technologies for teaching and learning and developed innovative solutions to their problems. ICT has emerged as an essential factor in education during school closures. This is especially important as schools in many parts of the world are in the process of moving back to face-to-face instruction. Moving forward, we may see an enhanced use of ICT for instruction in the form of blended learning. Blended learning is the thoughtful integration of online and face-to-face instruction (Garrison & Vaughan, 2008). Consequently, the role of school science leaders will remain in flux as they continue to empower science teachers to take advantage of new technologies and support their transition to the 'new normal'. The new normal being the society that will emerge from the pandemic. Science teachers can be prepared and supported to use ICT to design and deliver pedagogically sound instruction and create learning experiences beyond what can be learned in a traditional classroom.

Shifting back to face-to-face instruction after the pandemic will require teachers to be supported to integrate ICT with teaching and learning strategically. Pre-service teachers can be prepared to teach using different instruction formats like online, blended, and face-to-face instruction. In-service teachers can be provided access to ongoing professional development to develop the skills and knowledge of meaningful technology integration. Professional learning networks can provide the space for teachers to collaborate and share their resources, learning, and experiences. The study has implications for preparing and supporting science teachers to respond to interruptions in education like school closures during natural disasters, snow days, social unrest, and other unprecedented circumstances that cause disruptions in the education systems. It remains to be seen how school science leaders maintain their knowledge and practices cultivated during the COVD-19 pandemic and leverage their learning from the pandemic to the future.

References

Aguliera, E., & Nightengale-Lee, B. (2020). Emergency remote teaching across urban and rural contexts: perspectives on educational equity. *Information and Learning Sciences*.

Alvarez Jr, A. V. (2020). The phenomenon of learning at a distance through emergency remote teaching amidst the pandemic crisis. *Asian Journal of Distance Education, 15*(1), 144-153.

Banilower, E. R., Heck, D. J., & Weiss, I. R. (2007). Can professional development make the vision of the standards a reality? The impact of the national science foundation's local systemic change through teacher enhancement initiative. *Journal of Research in Science Teaching, 44*(3), 375-395. https://doi.org/https://doi.org/10.1002/tea.20145

Bianchini, J. A. (2012). Teaching while still learning to teach: Beginning science teachers' views, experiences, and classroom practices. In *Second international handbook of science education* (pp. 389-399). Springer.

Blatt, D. A. (2002). *A study to determine the relationship between the leadership styles of career technical directors and school climate as perceived by teachers*. West Virginia University.

Bourdieu, P. (1986). The forms of capital. In J. G. Richardson (Ed.), *Handbook of theory and research for the sociology of education.* Greenwood Press, Inc.

Bozkurt, A., & Sharma, R. C. (2020). Emergency remote teaching in a time of global crisis due to CoronaVirus pandemic. *Asian Journal of Distance Education, 15*(1), i-vi.

Buabeng-Andoh, C. (2012). Factors influencing teachersâ adoption and integration of information and communication technology into teaching: A review of the literature. *International Journal of Education and Development using ICT, 8*(1).

Burgos, D., Tlili, A., & Tabacco, A. (2021). *Radical Solutions for Education in a Crisis Context*. https://doi.org/10.1007/978-981-15-7869-4

Coleman, J. S. (1988). Social capital in the creation of human capital. *American journal of sociology, 94*, S95-S120.

Creswell, J. W. (2008). *Educational research: Planning, conducting, and evaluating quantitative*. Prentice Hall Upper Saddle River, NJ.

Dawes, L. (2001). What stops teachers using new technology? Teoksessa M. Leask (toimit.), Issues in Teaching Using ICT (s. 61–79).

Desimone, L. M. (2009). Improving Impact Studies of Teachers' Professional Development: Toward Better Conceptualizations and Measures. *Educational Researcher, 38*(3), 181-199. https://doi.org/10.3102/0013189x08331140

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis, 24*(2), 81-112.

Eraut, M. (1997, 1997/11/01). Perspectives on defining 'The Learning Society'. *Journal of Education Policy, 12*(6), 551-558. https://doi.org/10.1080/0268093970120609

Ferri, F., Grifoni, P., & Guzzo, T. (2020). Online learning and emergency remote teaching: Opportunities and challenges in emergency situations. *Societies, 10*(4), 86.

Gamoran, A., Secada, W. G., & Marrett, C. B. (2000). The organizational context of teaching and learning. In *Handbook of the sociology of education* (pp. 37-63). Springer.

Garrison, D. R., & Vaughan, N. D. (2008). *Blended learning in higher education: Framework, principles, and guidelines*. John Wiley & Sons.

Goolamally, N., & Ahmad, J. (2014). Attributes of School Leaders Towards Achieving Sustainable Leadership: A Factor Analysis. *Journal of Education and Learning, 3*(1), 122-133.

Grossman, P., & Thompson, C. (2008). Learning from curriculum materials: Scaffolds for new teachers? *Teaching and teacher education, 24*(8), 2014-2026.

Guskey, T. R. (2002, 2002/08/01). Professional Development and Teacher Change. *Teachers and Teaching, 8*(3), 381-391. https://doi.org/10.1080/135406002100000512

Hargittai, E., & Hsieh, Y. P. (2013). Digital inequality. In W. H. Dutton (Ed.), *The Oxford handbook of internet studies*. OUP Oxford.

Harris, A. (2020). COVID-19–school leadership in crisis? *Journal of Professional Capital and Community*.

Harris, A., & Jones, M. (2020). COVID 19–school leadership in disruptive times. *School Leadership & Management, 40*, 243-247.

Hartinah, S., Suharso, P., Umam, R., Syazali, M., Lestari, B., Roslina, R., & Jermsittiparsert, K. (2020). Retracted: Teacher's performance management: The role of principal's leadership, work environment and motivation in Tegal City, Indonesia. *Management Science Letters, 10*(1), 235-246.

Hennessy, S., Ruthven, K., & Brindley, S. (2005). Teacher perspectives on integrating ICT into subject teaching: commitment, constraints, caution, and change. *Journal of curriculum studies, 37*(2), 155-192.

Henze, I., van Driel, J. H., & Verloop, N. (2009). Experienced science teachers' learning in the context of educational innovation. *Journal of Teacher Education, 60*(2), 184-199.

Hirsh, S. (2001). We're Growing and Changing. *Journal of Staff Development, 22*(3), 10-13.

Kapborg, I., & Berterö, C. (2002). Using an interpreter in qualitative interviews: does it threaten validity? *Nursing inquiry, 9*(1), 52-56.

Kennedy, M. M. (2016). How does professional development improve teaching? *Review of Educational Research, 86*(4), 945-980.

Kirk, J., Miller, M. L., & Miller, M. L. (1986). *Reliability and validity in qualitative research* (Vol. 1). Sage.

Lee, O., Llosa, L., Jiang, F., O'Connor, C., & Haas, A. (2016). School resources in teaching science to diverse student groups: An intervention's effect on elementary teachers' perceptions. *Journal of Science Teacher Education, 27*(7), 769-794.

Leithwood, K., Harris, A., & Hopkins, D. (2020). Seven strong claims about successful school leadership revisited. *School Leadership & Management, 40*(1), 5-22.

Leithwood, K., & Jantzi, D. (2008). Linking leadership to student learning: The contributions of leader efficacy. *Educational administration quarterly, 44*(4), 496-528.

Luft, J. A., Dubois, S. L., Nixon, R. S., & Campbell, B. K. (2015). Supporting newly hired teachers of science: Attaining teacher professional standards. *Studies in Science Education, 51*(1), 1-48.

Merriam, S. B. (2009). Qualitative Research: A Guide to Design and Implementation.

Miles, M. B., Huberman, A. M., & Saldana, J. (2020). *Qualitative data analysis: A methods sourcebook* (Fourth edition ed.). SAGE.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2020). *Qualitative data analysis: A methods sourcebook* (Fourth Edition ed.). Sage publications.

Mumford, M. D., Zaccaro, S. J., Connelly, M. S., & Marks, M. A. (2000). Leadership skills: Conclusions and future directions. *The Leadership Quarterly, 11*(1), 155-170.

Napier, J. B., Luft, J. A., & Singh, H. (2020). In the classrooms of newly hired secondary science teachers: The consequences of teaching in-field or out-of-field. *Journal of Science Teacher Education, 31*(7), 802-820.

National Research Council. (2006). *America's lab report: Investigations in high school science* (0309139341).

Navy, S. L., Nixon, R. S., Luft, J. A., & Jurkiewicz, M. A. (2020). Accessed or latent resources? Exploring new secondary science teachers' networks of resources. *Journal of Research in Science Teaching, 57*(2), 184-208.

Newhouse, P. (2002). Literature review: The impact of ICT on learning and teaching. *Perth, Western Australia: Department of Education*.

NextGenScience. (2020). *Science Learning During COVID-19 and Beyond* https://wested.ent.box.com/s/4p1uh4obkh2djvo245o69lpyy1swe78j

OECD. (2021). *The State of School Education: One Year into the COVID Pandemic*. https://doi.org/10.1787/201dde84-en.

Oliveira, L., Mesquita, A., Sequeira, A., & Oliveira, A. (2021). Emergency Remote Learning during COVID-19: socio-educational impacts on Portuguese students. *Educating Engineers for Future Industrial Revolutions, 1328*, 303.

Özden, M. (2007). Problems with science and technology education in Turkey. *Eurasia Journal of Mathematics, Science and Technology Education, 3*(2), 157-161.

Park, H., Khan, S., & Petrina, S. (2009). ICT in Science Education: A quasi-experimental study of achievement, attitudes toward science, and career aspirations of Korean middle school students. (8), 993.

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications.

Pil, F. K., & Leana, C. (2009). Applying organizational research to public school reform: The effects of teacher human and social capital on student performance. *Academy of Management Journal, 52*(6), 1101-1124.

Rivera Maulucci, M. S. (2010). Resisting the marginalization of science in an urban school: Coactivating social, cultural, material, and strategic resources. *Journal of Research in Science Teaching, 47*(7), 840-860.

Saldaña, J. (2016). The coding manual for qualitative researchers.

Seidman, I. (2013). Interviewing and qualitative research: A guide for researchers in education and the social 2018 SAGE Publications, Ltd. *All Rights Reserved*.

Shea, L. M., Sandholtz, J. H., & Shanahan, T. B. (2018). We are all talking: A whole-school approach to professional development for teachers of English learners. *Professional Development in Education, 44*(2), 190-208.

Shim, T. E., & Lee, S. Y. (2020). College students' experience of emergency remote teaching due to COVID-19. *Children and youth services review, 119*, 105578.

Shulman, L. (1987). Knowledge and Teaching: Foundations of the New Reform. *Harvard Educational Review, 57*(1), 1-23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Singh, H., Luft, J. A., & Napier, J. B. (2021). The development of ePCK of newly hired in-field and out-of-field teachers during their first three years of teaching. *European Journal of Teacher Education*, 1-16.

Sperry, L. (2002). *Effective Leadership: Strategies for Maximizing Executive Productivity and Health*. Psychology Press.

Spillane, J. P., & Thompson, C. L. (1997). Reconstructing conceptions of local capacity: The local education agency's capacity for ambitious instructional reform. *Educational Evaluation and Policy Analysis, 19*(2), 185-203.

Tarhini, A., Arachchilage, N. A. G., & Abbasi, M. S. (2015). A critical review of theories and models of technology adoption and acceptance in information system research. *International Journal of Technology Diffusion (IJTD), 6*(4), 58-77.

The Harvard Gazette. (2020). *Time to fix American education with race-for-space resolve.* . https://news.harvard.edu/gazette/story/2020/04/the-pandemics-impact-on-education/

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2008). *Teacher professional learning and development* (Vol. 18). Citeseer.

Toprakci, E. (2006). Obstacles at integration of schools into information and communication technologies by taking into consideration the opinions of the teachers and principals of primary and secondary schools in Turkey. *Journal of Instructional Science and Technology (e-JIST), 9*(1), 1-16.

Tracy, S. J. (1996). The Structural and Functional Implications of a School District's Creation of Subject Area Supervisor Positions. *Journal of Personnel Evaluation in Education, 10*(4), 297-312.

Trust, T., & Whalen, J. (2020). Should teachers be trained in emergency remote teaching? Lessons learned from the COVID-19 pandemic. *Journal of Technology and Teacher Education, 28*(2), 189-199.

UNESCO. (2020). *COVID-19 education response: Preparing the reopening of schools: resource paper*. https://unesdoc.unesco.org/ark:/48223/pf0000373401

Vangrieken, K., Meredith, C., Packer, T., & Kyndt, E. (2017). Teacher communities as a context for professional development: A systematic review. *Teaching and teacher education, 61*, 47-59.

Watson, S. A., Huang, Y., Singh, H., Ozen-Tasdemir, H., Worth, E., McNeil, L., Luft, J.A., & Whitworth, B. A. (2020, March). *Practices, attributes, and knowledge of district science coordinators: Building a trajectory.* [Graduate Student Research Symposium] National Association of Research in Science Teaching, Portland, OR. (Conference canceled)

Whitworth, B. A., & Chiu, J. L. (2015). Professional Development and Teacher Change: The Missing Leadership Link. *Journal of Science Teacher Education, 26*(2), 121-137. https://doi.org/10.1007/s10972-014-9411-2

Whitworth, B. A., Maeng, J. L., Wheeler, L. B., & Chiu, J. L. (2017). Investigating the role of a district science coordinator. *Journal of Research in Science Teaching, 54*(7), 914-936.

Winzenried, A., Dalgarno, B., & Tinkler, J. (2010). The interactive whiteboard: A transitional technology supporting diverse teaching practices. *Australasian Journal of Educational Technology, 26*(4).

World Bank. (2020). *Remote Learning and COVID-19 The use of educational technologies at scale across an education system as a result of massive school closings in response to the COVID-19 pandemic to enable distance education and online learning.* . https://documents1.worldbank.org/curated/en/266811584657843186/pdf/Rapid-Response-Briefing-Note-Remote-Learning-and-COVID-19-Outbreak.pdf

Yoon, S., Koehler Yom, J., Yang, Z., & Liu, L. (2017). The effects of teachers' social and human capital on urban science reform initiatives: Considerations for professional development. *Teachers College Record, 119*(4), 1-32.

Zimmerman, J. (2020). Coronavirus and the great online-learning experiment. *Chronicle of Higher Education, 10*.

CHAPTER 4

CONCLUSIONS

This is the concluding chapter of my dissertation, where I bring the two studies together in discussing their contribution to the field, and my plan for future research that builds on this dissertation.

Summary

There are many challenging conditions for teachers. One condition is when teachers are assigned to a content area that is outside of their expertise. In this setting, a teacher is responsible for the enactment of lessons in a content area in which the teacher has limited expertise. A developing body of research shows that when teachers are outside of their expertise, there are implications for students and teachers (Berry et al., 2009; Darling-Hammond, 2000; Du Plessis, 2015; Du Plessis et al., 2017; Fitchett et al., 2019; Hobbs, 2013; Stronge, 2013). When teachers do not have adequate knowledge in the area of their assigned instruction, they are characterized as out-of-field (OOF) in their instructional area. This specifically happens when there is a mismatch between teachers' areas of expertise and teaching assignments (Ingersoll, 1998).

Another challenging condition is when teachers are assigned to a new instructional format related to the context in which they work. In this setting, a teacher can be knowledgeable but unfamiliar with adapting the content to the setting to best support student learning. These challenging conditions can constrain the work of teaching in different ways. When teachers do not have expertise in the context in which they are working, they could be characterized as OOF in context. This could happen when teachers are moved to new schools with different student demographics or when teachers are thrust into the online environment (in the case of the pandemic).

Among the teachers who are most vulnerable in these different conditions are newly hired teachers. Newly hired science teachers are just entering the workforce, and they are in the process of building and improving their knowledge for teaching. For these teachers, the first years play a significant role in the development of the knowledge they need for teaching (Luft et al., 2011). This includes their pedagogical knowledge, which grows significantly over time while working in a classroom (Mulholland & Wallace, 2005; Findlay & Bryce, 2012). Research on pedagogical content knowledge (PCK) of newly hired teachers has conflicting evidence about the presence and quality of PCK. While some studies indicate that PCK changes considerably during the first years of teaching (Lee et al., 2007; Luft et al., 2011; Monte-Sano & Budano, 2013), other studies divulge that PCK does not change in the first years of teaching (Friedrichsen et al., 2009). Studies reveal inconsistencies between new science teachers' conceptual science knowledge and practice (Greenwood, 2003; Lederman, 1999). Another challenging situation for newly hired teachers is the changing assignments from year to year, resulting in different levels of experience in a particular subject.

When newly hired teachers are OOF, it adds a layer of complexity to the already challenging situation. OOF teaching is demanding for both beginning and experienced teachers. However, OOF teaching can put more demands on beginning teachers because they lack both the experience and qualifications for teaching. When newly hired teachers are OOF, they lack the opportunity to build a strong foundation of knowledge, practices, or attributes (Sharplin, 2014). Experienced science teachers draw on their well-developed pedagogical knowledge from their discipline of specialization when teaching OOF (Sanders et al., 1993). However, when newly hired teachers are OOF, they do not have adequate pedagogical knowledge to fall back on (Wolff et al., 2015). For example, Napier et al. (2020) found that newly hired OOF science teachers to be at a greater risk of using isolated scientific instructional practices and low-level science instruction than their in-field counterparts. Over time, this limited foundation may have unintended consequences in their development as teachers.

This dissertation is a step towards understanding how different OOF conditions impact early-career science teachers. One study explores the impact of OOF teaching on the development of PCK of early career teachers during the first three years of teaching. PCK is the unique knowledge that is needed to transform knowledge into practice (Shulman, 1987). In this study, the focus is on enacted PCK (ePCK), which consists of the knowledge and skills used by a teacher in teaching a topic or aspect of a discipline. Teachers' ePCK is responsible for the decisions they make in terms of representing science to their students (Carlson et al., 2019). Unfortunately, little is known about the ePCK of newly hired teachers. It is essential to understand the development of ePCK of newly hired teachers because it provides an insight into how newly hired in-field or OOF teachers build their instructional knowledge and skills.

The other study focuses on being OOF in the area of context. In recognizing the important role of context, this study focuses on how teachers are resilient-even when they are outside of their context expertise. It specifically explores how international school science coordinators (SCs) supported (or not) science teachers' instruction when they are moved out of their familiar context. This is what happened when science teachers were ushered to distance learning platforms during the COVID-19 pandemic. Understanding the potential role of SCs in this setting is important to the instruction of teachers. Additionally, this type of study can shed light on how to support newly hired teachers in this challenging setting. The study provides insights into SCs navigate contextual shifts while supporting science teachers, and the resources that they draw upon while supporting the teachers.

The study adds to the limited literature that exists in the area. While OOF teaching has been recognized as a problematic phenomenon for more than two decades, there is limited research that looks into the classroom practices of OOF teachers. Not much is known about how OOF teachers build their knowledge for teaching. On the other hand, teaching and learning during the COVID-19 pandemic have been unprecedented, unique, and recent. There is minimal existing research on school systems shifting to the online format on a large scale and on short notice. Research on how the shift in instruction has influenced the resilient experiences of science leaders is non-existent. This study will add to the literature in the area.

Implications of the Study

OOF in Context

This dissertation highlights the importance of context in the development and application of science teachers' knowledge for teaching. The first study explored the development of ePCK of in-field and OOF teachers during the first three years of their teaching. The fluctuating nature of in-field and OOF teachers' ePCK may be attributed to their varying experiences within the dynamic context of teaching. Different experiences may impact the development of teachers' PCK (Kind & Chan, 2019). The second study explored the resilient experiences of science coordinators in supporting science teachers in the context of using distance learning as a platform of instruction during the COVID-19 pandemic. Administrators have had little time to prepare teachers for this swift and unprecedented shift in instruction. Teachers had little time to acquire and upgrade their information and communication technology (ICT) skills. Science coordinators (SCs) may not have been adequately prepared themselves for the dynamic role. This sudden change in context caught the entire school system off guard and may have been challenging for teachers and those who support them.

Historically, knowledge of context has been recognized as an essential professional knowledge base for teaching. Shulman (1987) placed PCK and knowledge of context among the seven knowledge bases for teaching. Grossman (1990) defined four areas of teacher knowledge. These too include PCK and knowledge of context. Since then, the science education community has continued to research and reconceptualize PCK. The latest model of PCK, the refined consensus model (RCM), also highlights the need for teachers to have a deep knowledge of context. RCM places teachers' development and application of PCK within the more extensive context, which acts as filters and amplifiers for developing and using teachers' knowledge and skills (Carlson et al., 2019). In this model, context refers to the factors that characterize and mediate learning. Technological Pedagogical Content Knowledge (TPACK) framework is teachers' knowledge base to teach effectively using technology. In recognition of the situated nature of teaching with technology, Koehler & Mishra (2008) identified context as an indispensable part of TPACK.

A sudden shift in the context of teaching can make teachers OOF in context. There are various ways in which the context of teaching can change. One such situation was experienced during the pandemic when teachers shifted to the distance learning platform without sufficient knowledge and preparation. In such a case, teachers may be teaching within their area of specialization yet may have limited knowledge of the changed context of teaching using technology. These teachers may not be able to produce the desired outcomes in new contexts. Research indicated that the use of digital technologies (as in the pandemic) might not necessarily translate into student-centered instruction (So & Kim, 2009). Another example of changing context is teacher reassignments to different grade levels or subjects. This situation can be challenging for teachers as they encounter new subject matter, a new set of standards, and new curriculum materials. Consequently, teachers can find themselves underprepared in the same manner as OOF teachers. At the elementary level, this phenomenon is documented as 'within school churn' in which teachers remain within their same school but are assigned a new grade level (Blazar, 2015). Changing the teaching context can be challenging for teachers, influence the development and use of their knowledge for teaching, and make teachers OOF.

Supporting Newly Hired and OOF Science Teachers

This study also has implications for supporting teachers teaching outside their expertise. These teachers include science teachers who are OOF field in their instructional area and science teachers OOF in the context of transitioning to online instruction. In either of these conditions, supporting early-career science teachers is essential. One way of supporting newly hired OOF science teachers is the guidance and support they receive from administrators and mentors. Administrators appoint and assign OOF teachers according to the requirements of the school. Subject-specific mentors provide specific support to newly hired teachers in the area of instruction. These mentors have been effective in supporting newly hired science teachers (Bang & Luft, 2014). Changing context may lead to a gap between what newly hired OOF teachers need and the support system that is available to them. In such a case, it may be beneficial for OOF teachers to have mentors beyond their first year of teaching and in all the subject areas they are OOF.

Another way of supporting OOF science teachers in the early years of their teaching is providing access to professional development programs that emphasize the development of their ePCK, pPCK, and TPACK. Professional learning programs can provide OOF teachers with space for developing their knowledge and practices (Ríordáin et al., 2019). Such opportunities may not be easily accessible to teachers in isolated, small, and rural schools (Ríordáin et al., 2019). These schools have a few science teachers who may be responsible for teaching all science subjects. OOF teachers may teach a combination of subjects and grades, with the assignments changing from year to year. Access to virtual professional learning programs has the advantage of connecting isolated OOF teachers with their peers and subject specialist mentor teachers and help teachers pool their resources and overcome issues of time and access (Salazar et al., 2010).

SCs have played an important role in supporting science teachers in various ways during the pandemic. However, the SCs themselves may have been equally unprepared as the teachers, as the context of their work changed too. In such circumstances, they may or may not have effectively supported science teachers' instructional practices during the pandemic. The effectiveness of the role of SCs is outside the scope of this study. SCs' work in supporting teachers within their constraints highlights the knowledge of technology and practice of collaboration that is essential in supporting science teachers in the online environment. Understanding these shifts in beneficial knowledge and practices of SCs will help support science teachers during and after the pandemic.

The role of science coordinators will remain in flux as they continue to support and empower science teachers to use new technologies and transition to the new normal. The new normal would be the society that will emerge from the pandemic. Education in the post-pandemic world may not look the same as before. This would make the pandemic a turning point in education systems worldwide. We may see an enhanced role of ICT for instruction in the form of blended learning. Consequently, teachers would need to be supported for pedagogies of ICT integration in science instruction. It is essential to continue to support the well-being, resilience, and social-emotional competencies of teachers (UNESCO, 2020c). Teachers can be provided ongoing professional development to upskill their knowledge of meaningful ICT integration with science instruction. Professional learning networks can provide teachers with the space to collaborate and share their experiences, learning, and resources. The duration and configuration of such professional learning programs is an area worth further exploration. The changing role of science leaders is worthy of further investigation.

Preparing Pre-Service Science Teachers

The study has implications for preparing preservice science teachers to respond to interruptions in education due to school closures. These interruptions could result from natural disasters, snow days, social unrest, war, and other unprecedented circumstances. Evaluating what worked during the pandemic and what did not would be beneficial in preparing and supporting teachers for future crises. The pandemic has brought into focus the reforms needed at the preservice education level. UNESCO (2020c) recommends modernizing teacher education programs through pedagogical and curricular innovations and high-quality reforms. This could include an emphasis on rehearsals of NGSS areas, developing ICT competencies for pedagogy, and preparing preservice teachers for distance learning.

In preparing preservice teachers, educators need to help build preservice teachers' pPCK, ePCK, TPACK, and subject matter knowledge (SMK) to levels that can support instruction during the early years of teaching. In science, this involves preservice teachers experiencing different disciplinary topics using reform-based teaching and learning approaches. This should help preservice teachers build their pPCK, which in turn will impact their ePCK. Understanding how the linkages are made within pPCK, which can influence ePCK, is an area ripe for study among science educators.

Major Contributions of the Study

Manuscript 1

This longitudinal study is the first to report the development of ePCK of newly hired OOF science teachers. There is a dearth of research on the knowledge and practices of OOF teachers and how these could impact student learning. Within the domain of teacher knowledge, PCK plays a vital role in understanding and improving science teaching (Shulman, 1986). The refined consensus model provides the theoretical framing of the study, which identifies ePCK as a distinct form of PCK that consists of knowledge and skills that guide classroom instruction (Carlson et al., 2019). Existing research on newly hired teachers focuses on PCK in general. The emerging literature on the relatively new constructs of ePCK and pPCK focus on describing ePCK and pPCK, how factors impact them in the school environment, and how they are developed (Carpendale & Hume, 2019; Coetzee et al., 2020; Hanuscin et al., 2020; Mazibe et al., 2020). This study provides an insight into how newly hired in-field and OOF teachers build their ePCK over time. The findings of this study align with and add to the research that reports that PCK develops significantly during the early years of teaching (Lee et al., 2007; Luft et al., 2011; Monte-Sano & Budano, 2013).

From this study, we found that teaching OOF in the early years of their career impacted the development of science teachers' ePCK. OOF settings prevented early career teachers from strengthening their ePCK over time. For example, in-field teachers successfully created an environment for understanding science concepts and seeing how science proceeds. On the contrary, OOF teachers focused more on teaching of facts and definitions associated with topics.

OOF teachers' limited SMK likely limited their ePCK. The OOF teachers may have lacked the foundational connections within the disciplines they taught, leading to a limited representation of the topics they taught. For OOF teachers, variations in their SMK and in the duration of teaching OOF impacted their ePCK. Over the three years of the study, the fluctuating nature of ePCK of in-field and OOF teachers were observed. This indicated that they were building their knowledge of teaching. Researchers have reported similar findings of the changes in general PCK of newly hired teachers (e.g., Lee et al., 2007; Luft et al., 2011). The variations in ePCK of newly hired science teachers resulted from varying experiences with the content and context of the curriculum, peers, and students. The examination of ePCK in the study revealed that being OOF mattered for newly hired science teachers.

Manuscript 2

A significant contribution of this study is in understanding the role of science coordinators in supporting science teachers during the pandemic. Burgos et al. (2021) recognize school leadership as equally important as knowledge of pedagogy and technology during the pandemic. The pandemic being current, unprecedented, and sudden, research on the impact of the pandemic on teaching and learning is emerging. Empirical research published on teaching online during the pandemic examines the experiences of students and educators, inequity faced by learners, and opportunities and challenges of shifting to online education at short notice (Abel, 2020; Aguliera & Nightengale-Lee, 2020; Ferri et al., 2020; Oliveira et al., 2021; Shim & Lee, 2020; Trust & Whalen, 2020). These studies are situated in the local context. No study published so far has investigated the experiences of school leaders during the pandemic. This dissertation adds to the research by providing a unique perspective into science coordinators' work and experiences at the international level.

This dissertation provides a unique insight into the knowledge, practices, and attributes (KPA) of SCs and the resources they drew upon while supporting science teachers during the pandemic. SCs drew upon material and social resources to support science teachers. The KPA important to SCs during the pandemic involved working with people. This underscores the importance of building interpersonal attributes in school leaders and teachers. SCs' KPA translated as social and material resources, and likely their human resources. Between these resources, social resources emerged as the most important in supporting science teachers to teach online during the pandemic. Social resources, in turn, provided opportunities for teachers to interact with colleagues and work collaboratively to discuss their work, generate material resources, share expertise, and build their knowledge of teaching and learning in the online environment (material and human resources). Teachers could build their pedagogical knowledge, pedagogical content knowledge, technological pedagogical content knowledge, and knowledge of reform-based instructional practices through the process.

Another significant contribution of this study is identifying knowledge of ICT and the practice of collaboration as integral to the work of SCs. Participants identified the pandemic as an opportunity to explore online teaching and learning, facilitate collaboration between and with teachers, and an opportunity for students to manage their learning. SCs were involved in preparing teachers to address the students' academic needs and responding to their psychological needs. SCs anticipated technology as an important agent in post-pandemic teaching and learning. Learnings from the pandemic may help develop a coherent online and blended learning strategy. UNESCO (2020a) advocates this as an opportunity to rethink the intention, content, role, and delivery of education to prepare education systems to deal with emergencies in the future. As educational systems stabilize to a new normal, it may be an opportunity to rethink the education system to be more inclusive, equitable, and resilient (UNESCO, 2020b).

Future Research

Little is known about what makes some teachers approach the challenges of their OOF assignment with a positive mindset, improve their SMK, gain confidence in teaching the OOF subject, and start enjoying it. OOF teachers have reported that they start feeling in-field and love to teach the OOF subject after teaching it for several years (Du Plessis, 2016). With time, OOF teachers can transition into expert teachers in the OOF subjects. However, it remains to be seen how the intensity of being OOF changes from a new OOF teacher to feeling like an experienced in-field teacher. I am interested in exploring what it is about these teachers, the context of their work, or a combination of the two that makes the transition from OOF to in-field possible and seamless.

Professional development and professional learning opportunities help engage teachers and school leaders in new learning about their professional practice, which bring about a change in their thinking, knowledge, skills, and instructional approaches (Villegas-Reimers, 2003; OECD, 2009). While extensive research exists on professional development and professional learning, it does not particularly explore the opportunities for OOF teachers. We know that the structural features of PD like form and duration are consistent for OOF and in-field teachers. In contrast, the core features such as a focus on content knowledge, active learning opportunities, and needs and expectations differ between in-field and OOF teachers (Faulkner et al., 2019). OOF teachers have been found to need continuing professional learning opportunities (Faulkner et al., 2019). Virtual professional learning communities have been found to helpful in transcending the barriers of time and space faced by many teachers (McConnell et al., 2013). For

OOF teachers, virtual professional learning programs have the potential of not only connecting isolated OOF teachers with their peers and subject specialist mentor teachers but help teachers pool their resources and overcome issues of time and access. In my future research, I hope to understand how online and ongoing professional learning programs and communities help support OOF teachers and how OOF teachers build their pPCK and ePCK while immersed in these virtual professional learning communities.

Science leaders play an essential role in supporting science teachers. In the context of the altered education systems during the COVID-19 pandemic, exploring science leaders' supports and PD needs is crucial for supporting science teachers. Whitworth & Chiu (2015) found school and district science leaders as the missing link from the current models of PD. The influence of science leaders in developing the pPCK and ePCK of science teachers teaching outside their expertise and their use of reform-based instructional practices is worthy of further investigation.

References

Abel Jr, A. (2020). The phenomenon of learning at a distance through emergency remote teaching amidst the pandemic crisis. *Asian Journal of Distance Education*, *15*(1), 127-143.

Aguliera, E., & Nightengale-Lee, B. (2020). Emergency remote teaching across urban and rural contexts: perspectives on educational equity. *Information and Learning Sciences*.

Bang, E., & Luft, J. A. (2014). Exploring the written dialogues of two first-year secondary science teachers in an online mentoring program. *Journal of Science Teacher Education*, *25*(1), 25-51.

Berry, B., Daughtrey, A., & Wieder, A. (2009). Teaching Effectiveness and the Conditions that Matter Most in High-Needs Schools: A Policy Brief. *Center for Teaching Quality*.

Blazar, D. (2015). Grade assignments and the teacher pipeline: A low-cost lever to improve student achievement? *Educational Researcher, 44*(4), 213-227.

Burgos, D., Tlili, A., & Tabacco, A. (2021). Education in a Crisis Context: Summary, Insights and Future. In *Radical Solutions for Education in a Crisis Context* (pp. 3-10). Springer, Singapore.

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

Carpendale, J., & Hume, A. (2019). Investigating practising science teachers' pPCK and ePCK development as a result of collaborative CoRe design. In *Repositioning pedagogical* *content knowledge in teachers' knowledge for teaching science* (pp. 223-250). Springer, Singapore.

Coetzee, C., Rollnick, M., & Gaigher, E. (2020). Teaching Electromagnetism for the First Time: a Case Study of Pre-service Science Teachers' Enacted Pedagogical Content Knowledge. *Research in Science Education*, 1-22.

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Education policy analysis archives*, *8*(1), 1-44.

Du Plessis, A. E. (2015). Effective education: Conceptualizing the meaning of out-of-field teaching practices for teachers, teacher quality and school leaders. *International journal of educational research, 72*, 89-102.

Du Plessis, A. E. (2016). Leading teachers through the storm: Looking beyond the numbers and turning the implications of out-of-field teaching practices into positive challenges. *International journal of educational research, 79*, 42-51.

Du Plessis, A. E., Carroll, A., & Gillies, R. M. (2017). The meaning of out-of-field teaching for educational leadership. *International Journal of Leadership in Education, 20*(1), 87-112.

Faulkner, F., Kenny, J., Campbell, C., & Crisan, C. (2019). Teacher learning and continuous professional development. In *Examining the Phenomenon of "Teaching Out-of-field"* (pp. 269-308). Springer, Singapore.

Ferri, F., Grifoni, P., & Guzzo, T. (2020). Online learning and emergency remote teaching: Opportunities and challenges in emergency situations. *Societies*, *10*(4), 86.

Findlay, M., & Bryce, T. G. K. (2012). From teaching physics to teaching children: Beginning teachers learning from pupils. International Journal of Science Education, 34,2727–2750.

Fitchett, P. G., McCarthy, C. J., Lambert, R. G., Eyal, M., Playfair, E. C., & Dillard, J. B. (2019). Examining teacher stress-vulnerability in the US secondary school context. *Educational Review*, 1-24.

Friedrichsen, Patricia J, Sandra K. Abell, Enrique M. Pareja, Patrick L. Brown, Deanna M. Lankford, and Mark J. Volkmann. 2009. "Does Teaching Experience Matter? Examining Biology Teachers' Prior Knowledge for Teaching in an Alternative Certification Program." *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching* 46 (4): 357-383.

Greenwood, A. M. (2003). Factors influencing the development of career-change teachers' science teaching orientation. *Journal of Science Teacher Education*, *14*(3), 217-234.

Grossman, Pamela Lynn. 1990. *The Making of a Teacher: Teacher Knowledge and Teacher Education*. Teachers College Press, Teachers College, Columbia University.

Hanuscin, D. L., de Araujo, Z., Cisterna, D., Lipsitz, K., & van Garderen, D. (2020). The re-novicing of elementary teachers in science? Grade level reassignment and teacher PCK. *Journal of Science Teacher Education*, *31*(7), 780-801.

Hobbs, L. (2013). Teaching 'out-of-field' as a boundary-crossing event: Factors shaping teacher identity. *International journal of science and mathematics education*, *11*(2), 271-297.

Ingersoll, R. M. (1998). The problem of out-of-field teaching. *The Phi Delta Kappan, 79*(10), 773-776.

Kind, V., & Chan, K. K. (2019). Resolving the amalgam: connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. *International Journal of Science Education*, *41*(7), 964-978.

Koehler, M. J., & Mishra, P. (2008). Introducing TPCK. In The AACTE Committee on Innovation and Technology (Ed.), *Handbook of technological pedagogical content knowledge (TPCK) for educators* (pp. 3–29). Routledge.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *36*(8), 916-929.

Lee, E., Brown, M. N., Luft, J. A., & Roehrig, G. H. (2007). Assessing beginning secondary science teachers' PCK: Pilot year results. *School Science and Mathematics*, *107*(2), 52-60.

Luft, J. A., Firestone, J. B., Wong, S. S., Ortega, I., Adams, K., & Bang, E. (2011). Beginning secondary science teacher induction: A two-year mixed methods study. *Journal of Research in Science Teaching*, *48*(10), 1199-1224.

Mazibe, E. N., Coetzee, C., & Gaigher, E. (2020). A comparison between reported and enacted pedagogical content knowledge (PCK) about graphs of motion. *Research in Science Education*, *50*(3), 941-964.

McConnell, T. J., Parker, J. M., Eberhardt, J., Koehler, M. J., & Lundeberg, M. A. (2013). Virtual professional learning communities: Teachers' perceptions of virtual versus face-to-face professional development. *Journal of science education and technology*, *22*(3), 267-277.

Monte-Sano, C., & Budano, C. (2013). Developing and enacting pedagogical content knowledge for teaching history: An exploration of two novice teachers' growth over three years. *Journal of the Learning Sciences*, *22*(2), 171-211.

Mulholland, J., & Wallace, J. (2005). Growing the tree of teacher knowledge: Ten years of learning to teach elementary science. *Journal of research in Science teaching*, *42*(7), 767-790.

Napier, Jessica B., Julie A. Luft, and Harleen Singh. 2020. "In the Classrooms of Newly Hired Secondary Science Teachers: The Consequences of Teaching In-Field or Out-of-Field." *Journal of Science Teacher Education* 31(7): 802-820.

Oliveira, L., Mesquita, A., Sequeira, A., & Oliveira, A. (2021). Emergency Remote Learning during COVID-19: socio-educational impacts on Portuguese students. *Educating Engineers for Future Industrial Revolutions*, *1328*, 303.

Organisation for Economic Cooperation & Development (OECD). (2009). Creating effective teaching and learning environments: First Results from TALIS. *Teaching and Learning International Survey*. Paris.

Ríordáin, M. N., Paolucci, C., & Lyons, T. (2019). Teacher professional competence: What can be learned about the knowledge and practices needed for teaching?. In *Examining the Phenomenon of "Teaching Out-of-field"* (pp. 129-149). Springer, Singapore.

Salazar, D., Aguirre-Munoz, Z., Fox, K., & Nuanez-Lucas, L. (2010). On-line professional learning communities: Increasing teacher learning and productivity in isolated rural communities. *Systemics, Cybernetics and Informatics*, *8*(4), 1-7.

Sanders, L. R., Borko, H., & Lockard, J. D. (1993). Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching, 30*(7), 723-736.

Sharplin, E. D. (2014). Reconceptualising out-of-field teaching: Experiences of rural teachers in Western Australia. *Educational Research, 56*(1), 97-110.

Shim, T. E., & Lee, S. Y. (2020). College students' experience of emergency remote teaching due to COVID-19. *Children and youth services review*, *119*, 105578.

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

Shulman, Lee. 1987. "Knowledge and Teaching: Foundations of the New Reform." *Harvard Educational Review* 57(1):1-23.

So, H.-J., & Kim, B. (2009). Learning about problem-based learning: student teachers integrating technology, pedagogy and content knowledge. *Australasian Journal of Educational Technology, 25*(1), 101–116.

Stronge, J. (2013). *Effective teachers= student achievement: What the research says*: Routledge.

Trust, T., Whalen, J. (2020). Should teachers be trained in emergency remote teaching? Lessons learned from the COVID-19 pandemic. *Journal of Technology and Teacher Education*, *28*(2), 189-199.

UNESCO. (2020a). COVID-19 Education Response: Preparing the reopening of schools. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000373401

UNESCO. (2020b). Distance learning strategies in response to COVID-19 school closures. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000373305/PDF/373305eng.pdf.multi

UNESCO. (2020c). UNESCO COVID19 Supporting teachers and education personnel during times of crisis. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000373338?posInSet=1&queryId=77eff0a2-4a0e-463b-aab7-a4433957e77f

Villegas-Reimers, E. (2003). *Teacher professional development: an international review of the literature*. Paris: International Institute for Educational Planning.

Whitworth, B. A., & Chiu, J. L. (2015). Professional development and teacher change: The missing leadership link. *Journal of Science Teacher Education*, *26*(2), 121-137.

Wolff, C. E., van den Bogert, N., Jarodzka, H., & Boshuizen, H. P. (2015). Keeping an eye on learning: Differences between expert and novice teachers' representations of classroom management events. *Journal of teacher education*, *66*(1), 68-85.

APPENDIX A

STUDY 1: PCK (PEDAGOGICAL CONTENT KNOWLEDGE) INTERVIEW PROTOCOL

Participant		Interviewer	
Induction Group		T1/T2/T3/T4	
Date		Recording Time	

1.	What do think constitutes a good lesson in science?
2.	Can you briefly describe how you taught ________________? *(Atomic structure, DNA, Newton's Laws, Earthquakes).*
3.	What did you consider when planning your lesson/unit?

If not explicitly mentioned – use the following probes	
i.	What did you consider about your students when designing these lessons?
ii.	Did you consider prior knowledge? If so, how?
iii.	Did you consider variations in students' approaches to learning? If so, how?
iv.	Did you consider students' difficulty with specific science concepts (misconceptions)? If so, how?
3.	Would you consider any part of the lesson that you just described to be inquiry? If not, how could you modify your lesson to be inquiry?

APPENDIX B

STUDY 1: CLASSROOM OBSERVATION PROTOCOL

I. Background Information

Teacher Name: __________________ School: _________________________

Subject Observed: __________________________ Grade Level: __________

Observation is (circle one): in-field/ out-of-field (based on major & content)

Start Time: ____________ End Time: ___________ Date :_______________

Schedule Type __________________ Block (60-over) __________________

# of classroom meetings a week _________________ 2-4 ________________

Observer: _____________________ Observation # (circle one) : 1 2 3 4

Number of students in class ____________

Brief description of students in class:

II. Contextual Background and Activities

A. Objective for lesson (ask teacher before observing)

B. How does lesson fit in the current context of instruction (e.g. connection to previous and other lessons)?

C. Classroom setting: (space, seating arrangements, room for the lesson, if desks are fixed or moveable, posters (science vs. non-science), student work, is it conducive to lab work (or teaching science) etc. Include a diagram).

D. Any relevant details about the time, day, students, or teacher that you think are important? Include diagram. (i.e.: teacher bad day, day before spring break, pep rally previous hour, etc.)

III. Description of events over time (indicate time when the activity changes)

Make sure that you describe the activity. If you can collect artifacts.

Time	Description of events

APPENDIX C

STUDY 1: WEEKLY UPDATE INTERVIEW AND CODING SHEET

Teacher Name: Interviewer:

Grade/Subject: If-Field / Out-of-field Date:

Schedule Type: Traditional (< 60 mins) Block (> 60 mins)

Class meets: Daily 2-4 days a week

Update# 1 2 3 4 5 6 7 8` 9

Interview questions (on even interviews, ask question 4)

1. How did things start this year? Compared to last year?
    a. As teacher talks about events, ask for more details.
    b. If good points are presented, ask about what is not going well? Or, if bad points are presented, as what is going well.
    c. How confident are you in your ability to motivate students? Assess their learning?

The goal of this probe is to capture the current issues for the teacher in terms of instruction

2. Have there been any changes in the professional development activities that you are engaging in since we last talked? If so—probe about the type of activity and the level participation (e.g., how often are you going, what are you doing in these meetings/events, serving as a mentor or beginning a mentee).
3. Have you taken on any new responsibilities since we last talked? If so, what are they? Were there any responsibilities that you declined this year? If so, what are they?

4. Is there any additional information that you would like to share regarding your teaching that we have not talked about, that would be helpful for us to know?

DAY	OBJECTIVE	ACTIVITIES/ STRATEGIES	MATERIALS	ASSESSMENTS
MONDAY DATE______				
TUESDAY DATE______				
WED DATE______				
THURS DATE______				
FRIDAY DATE______				

1. How do you feel these lessons went? What did you like about them? What would you do differently? (Trying to get at changes they would make per the lesson/teaching, or perceived strengths of lesson/teaching. May also indicate supplies that are present in class)

2. It's been busy, but good. I was impressed with how they did on Excel because they haven't had previous working knowledge of it. I'd probably plan my questioning better on Monday

because they really did have a lot of knowledge about it, I should've asked them before doing the definitions.

	Mon	Tues	Wed	Thurs	Fri
Lesson consisted of: Date:					
• Bell-work/Opening activity					
• Teacher-led lecture without discussion					
• Teacher-led class discussion					
• Teacher directions					
• Teacher-led demonstration					
• Teacher-led simulation					
• Teacher-led review activity- For test					
• Teacher-led review activity- hwk/prev. day					
• Teacher-led review activity of class assignment					
• Inquiry laboratory/activity					
• Guided inquiry laboratory/activity					
• Directed inquiry laboratory/activities					
• Verification laboratory/activity					
• Process / skills laboratory/activity					
• Student research project					
• Students reading assigned material					
• Students work/reading from a textbook					
• Students complete a worksheet					
• Student presentations					
• Video/film/DVD					
• Homework assigned					
• Homework collected					
• Out of class experience/field trip					
• Admin task					
• Non-science instruction					
• Interruption					
• No class					
• Other					
Classroom organization:					
• Individual					
• Whole group					
• Small group, 2-4 students					
• Cooperative learning					
• Lesson from previous year					
• Lesson from published source					

• Lesson is from school/district curriculum					
• Lesson from mentor/colleague					
• Lesson created by teacher					
• Lesson from Internet					
• Other					
Materials/Technology used:					
• Laboratory – Professional equipment					
• Laboratory - Common items					
• Computer - Internet					
• Computer - Software					
• Computer - PowerPoint					
• Probeware					
• Other (whiteboard)					
Assessments used: Date:					
• District/State assessment					
• Department assessment					
• End of Unit/Chapter Test (formal test)					
• Quiz					
• Rubric					
• Lab report					
• Interactions with students (questioning)					
• Multiple choice					
• Matching					
• Fill in the blank					
• Short answer					
• Essay					
• Lab journal/notebook/logbook					
• Other					

Descriptions:

<u>Under "Lesson consisted of"</u>

Bell work – To get students settled and focused, lasting a short period of time (approximately 5-10 mins), and having a set procedure (e.g., copying information from the board).

Teacher-led lecture without discussion – When the purpose of dialogue is to disseminate information. It includes questions by teacher and answers by student. Used as verification by teacher.

Teacher-led class discussion – When purpose is to promote dialogue between teacher and student. In this dialogue questions are open-ended and lead to discussion, interaction, and brainstorming.

Teacher led review – For test – This activity allows the students to review for the test and may include games, review discussions, or written review activities.

Teacher-led demonstration –To provide students with a visual or auditory experience to see a phenomena or event that they would otherwise not observe. Demonstrations can be conceptual or teach a skill.

Teacher-led simulations- Students apply concepts, analyze situations, solve problems, or understand different points of view. Typically, situations, concepts or issues are provided in a condensed and simplified form.

Reading assigned material – Students are reading materials that the teacher copies off, school magazines related to science, or articles. This is not coded when reading a textbook.

Inquiry laboratory/activity – The students develop their own question to explore, along with determining the experiment and modes of data collection.

Guided inquiry/activity – The teacher provides the question, and the students are free to answer the question as they see fit.

Directed inquiry laboratory/activity – The teacher provides the question and the mechanism to answer the question.

Verification laboratory/activity – The students are told or know the concepts they will see during the activity. They follow written/verbal guidelines to identify the concept.

Skill-based laboratory/activity – The laboratory/activity involves the learning of some basic skill (e.g. learning measurement).

Assignment – Discussion is of an assignment to be done outside of class (e.g. homework).

Administrative task – Large amount of time is spent in taking care of administrative tasks (e.g. stamping journals without another activity going on).

Non-science instruction – Large amount of time is spent on instruction that is not related to science.

<u>Under "Classroom organization"</u>

Individual – Students are working individually on a task (e.g. worksheet). The only interaction is with the teacher.

Whole group – Students are groups together as a class. This is coded with lecture or class discussion.

Group work 2-4 students – Students work together in groups of 2-4.

"Lesson from" – This should be coded who regard to who or what supplied the lesson. For example if a mentor teacher supplies a textbook lesson, it is coded as a mentor teacher.

Lesson from published source – Lesson is from outside of the school or district.

<u>Under "Assessments used"</u>

Lab journal/notebook/logbook – Used to assess students but is not used just in the scientific sense of the term "lab journal". Also used for questions, reflections, etc.

APPENDIX D

STUDY 2: INTERVIEW PROTOCOL

Thank you for completing our consent form. As a reminder, we are doing this research study to learn more about how school science coordinators or school science leaders have used their knowledge and practices to support science teachers as schools have shifted from in-person to distance learning. In particular, we will talk about the knowledge and practices that have been useful in the process, those that you have developed, support structure available to the science teachers, difficulties you have faced in the process, and how this has influenced student science learning experiences,

Your role in this study is to discuss your experiences in a leadership position in school science. These experiences will us develop an understanding of the knowledge and practices that are important for supporting and preparing teachers to teach in online distance learning environments. This would also be helpful in future disasters.

At this time, do you have any additional questions about the Consent Form, and the collection, analysis, and life of the data?

If you have no questions, I will begin audio recording this interview. Is this OK with you?

Interviewer: Today is XXXXX. I am XXXX, and I am interviewing XXXXXX.

If at any time in this process you don’t want to answer the questions, you can opt-out of answering it. If you want to end the interview at any time– you can just tell me you would like to stop.

The first set of questions are about the background and current position (demographics)

1. Tell me about your current position
    a. What is the exact title of the position you hold?
    b. Tell me about your school. Name. Area, rural/urban/number of students etc
    c. Does your school consider you an administrator?
    d. How many years have you been in this position? (History)
    e. How many teachers do you lead/supervise/support?
    f. Please describe your current position (are you teaching as well?)
        i. Which grade level are you responsible for?
        ii. What content areas are you responsible for?
2. Tell me about your background
    a. What is your highest degree?
    b. What kind of degree did you obtain? (physics, chemistry, biology...)
3. Have you participated in professional development?
    a. How often?
    b. What kind of professional development? (Conferences, online courses, courses etc)
    c. What topics are those professional developments? (leadership, content knowledge and so forth)
    d. Did you have access to any special professional development during this time? If so please explain.
4. What is the format of instruction/platform that your school has shifted to, during the pandemic?

5. Can you share some of your experiences as a science coordinator, during the pandemic?

The second set of questions about knowledge

1. What is the knowledge that is unique to you as a science coordinator? When I talk about knowledge, I am thinking of the types of knowledge you need to be successful in your position.
2. What knowledge as a teacher leader has been helpful to you during and after the transition of instruction from in-person to distance learning? Explain.
3. What knowledge have you developed during this time that you think is useful? Explain.

The third set of questions about practices

1. What are the practices unique to you as a science coordinator? When I talk about practices, I am thinking of the actions you need to take to be successful in your position.
2. What practices as a teacher leader has been helpful to you during and after the transition of instruction from in-person to distance learning? Explain.
3. What are the new practices that you have used or learned during this time? Explain. (example)
4. What types of support and/or professional development have you provided your science teachers during the time of the pandemic, to shift instruction online?
5. What kind of support/training has your school provided you during the time of the pandemic?
6. During the pandemic, how do/did you ensure that the teachers plan instruction that is pedagogically sound, and is not merely a transmission of knowledge? (student-centered instruction)

7. How do you support equitable access to the use of ICT (information and communications technology) by all your teachers and students? By access, I mean physical access as well as the quality of the teaching and learning experiences.
8. Are there any issues/challenges you have faced during the shifting of teaching from in-person to distance learning?
9. What is a major takeaway for you during this time? Something that you have learnt that you would like to continue in the post-pandemic schooling?

In closing

Is there anything else you would like to share?

We really appreciate your time. Would you like a copy of our paper, when we have it written? What email can we send it to?