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Adopting Drone Technology in STEM (Science, Technology, Engineering, and Mathematics): An Examination of Elementary Teachers' Pedagogical Content Knowledge

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Abstract In this case study, the authors collaborated with two grade 4 teachers, who participated in a large-scale professional learning program focused on helping K-9 teachers enhance their classroom practice and confidence in teaching science through inquiry-based learning. The specific research questions that guided the study were the following: (a) How do components of teachers' pedagogical content knowledge (PCK) change as they adopt drone technology in the context of a unit on habitats? (b) What challenges will the teachers encounter as they adopt inquiry-based approaches to teaching and learning using drone technology? and (c) What factors will influence the development of teachers' PCK? Using a multi-dimensional PCK framework, the authors report on changes in teachers' orientations to teaching science and knowledge of assessment, instructional strategies, science curriculum, and student learning. In addition, it was found that teacher efficacy and knowledge of student learning were highly connected factors that contributed to PCK growth and changes in classroom practice. As the teachers gained more insight into how to support student learning through the adoption of drones and inquiry-based approaches to teaching and learning, they strengthened their confidence and belief in their own ability to create classroom learning environments that could engage all learners in science. Challenges and implications related to the adoption of droned technology are also discussed.

Résumé Dans cette étude de cas, les auteurs ont collaboré avec deux enseignants de 4e année, qui ont participé à un vaste programme de perfectionnement professionnel visant à aider les enseignants de la maternelle à la 9e année à améliorer leurs pratiques d'enseignement et leur confiance en eux en enseignement des sciences, par le biais d'un apprentissage fondé sur la recherche. Les questions de recherche spécifiques qui ont guidé cette étude sont les suivantes: a) comment les éléments de connaissance des contenus pédagogiques (CCP) évoluent-ils chez les enseignants lorsque la technologie des drones est

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adoptée dans le contexte d'une unité d'enseignement / apprentissage sur les habitats? b) quels défis les enseignants devront-ils relever s'ils adoptent des approches d'enseignement et d'apprentissage basées sur l'investigation qui utilisent la technologie des drones? c) quels facteurs influencent le développement de la CCP des enseignants? À l'aide d'un cadre multidimensionnel en CCP, les auteurs rendent compte d'une évolution dans les orientations des enseignants en matière d'enseignement des sciences et dans leurs connaissances en matière d'évaluation, de stratégies pédagogiques, de curriculum scientifique et d'apprentissage des élèves. En outre, on constate que l'efficacité des enseignants et leur connaissance de l'apprentissage des élèves sont des facteurs étroitement liés qui contribuent au perfectionnement de la CCP ainsi qu'à une évolution des pratiques d'enseignement. Au fur et à mesure que les enseignants comprennent mieux comment soutenir l'apprentissage des élèves grâce à l'utilisation de drones et à l'adoption d'approches d'enseignement / apprentissage basées sur l'investigation, ils renforcent leur confiance en leur propre capacité de créer des environnements d'apprentissage en classe susceptibles d'engager tous les apprenants dans les sciences. Les défis et les implications liés à l'adoption de la technologie des drones sont également abordés.

Keywords Action research · Drone technology · Pedagogical content knowledge · Teacher professional learning

The use of inquiry-based, constructivist-based learning and the engagement of K-12 students in the practices of science have been and continue to be a strong priority in science curriculum documents internationally (Australian Curriculum, Assessment, and Reporting Authority, 2015; Council of Ministers of Education (Canada), 1997; Department of Education, 2015; Department of Education and Early Childhood Development, 2016; Ministry of Education-Singapore, 2013; National Research Council, 2012). Based on many research studies, researchers argue that inquiry-based teaching and learning, with appropriate scaffolding, can have positive impacts on student cognitive and affective learning outcomes (Alfieri et al., 2011; Furtak et al., 2012; Hmelo-Silver et al., 2007; Kidman & Casinader, 2017; Minner et al., 2010). It should also be noted that the nature of inquiry, how it should be structured to support student learning, and its value have been controversial (Clark et al., 2012; Kirschner et al., 2006; Zhang, 2016).

According to Minner et al. (2010), the term inquiry refers to three distinct categories of activities: what scientists do, how students learn, and the pedagogical approach used by teachers (p. 476). Everett & Moyer (2007) suggested that the key component of inquiry science instruction is the use of activities where students are actively "investigating a question to which they do not know the answer" (p. 54). Inquiry may take several forms such as confirmation, inquiry, structured inquiry, guided inquiry, or open inquiry (Banchi & Bell, 2008; Berg et al., 2003; Duschl & Grandy, 2008; Zion & Mendelovici, 2012). For example, a lab that reinforces a well-known phenomenon using a demonstration is considered confirmation inquiry.

The authors of this paper conceptualize teaching and learning through inquiry as a means to promote many forms of student learning in science. Furthermore, the authors do not view inquiry as a unity approach. Rather, they view it broadly, encompassing many approaches to instruction and occurring on a continuum in terms of the role of the teacher and the amount of student support provided. In the project described in this paper, teaching and learning through inquiry involves:

> Skills such as questioning, observing, inferring, predicting, measuring, hypothesizing, classifying, designing experiments, collecting data, analyzing data, and interpreting data are fundamental to engaging in science. These skills are often represented as a cycle which involves the posing of questions, the generation of possible explanations, and the collection of evidence to determine which

of these explanations is most useful in accounting for the phenomenon under investigation. (Department of Education, 2016, p. 19)

Despite the potential benefits of adopting inquiry-based approaches to teaching and learning in science, teachers struggle to adopt pedagogies that will foster learning through inquiry (Dobber et al., 2017; Mkimbili et al., 2017; Yoon et al., 2012; Zion et al., 2007). The concept of inquiry is "elusive for teachers" (Capps et al., 2016, p.956) and this causes confusion for both novice teachers (Chichekian et al., 2016) and experienced teachers (Capps et al., 2012). Inquiry tends to be student-centred, requiring teachers to act as facilitators of the inquiry learning and relinquish control to foster guided and independent learning (Goodnough et al., 2014; Goodnough 2016; DiBiase & McDonald, 2015; Dunkhase, 2003).

One way to gain insight into how primary/elementary teachers adopt inquiry-based teaching and learning is to examine their pedagogical content knowledge (PCK) and how it becomes engaged in practice. Teachers need to examine and transform their PCK if they are to create learning environments that are inquiry-based and student-centred.

In this case study, the authors collaborated with two grade 4 teachers, Lois and Sam (pseudonyms), who participated in a large-scale professional learning program, Teachers in Action, implemented in the Canadian province of Newfoundland and Labrador. The program focused on helping K-9 teachers enhance their classroom practice and confidence in teaching science through inquiry-based learning. The authors examined how the teachers' PCK developed as they adopted drone technology in the context of inquiry-based instruction.

Theoretical Framework

The notion of pedagogical content knowledge (PCK), conceptualized by Shulman (1987) and re-conceptualized by scholars in the area of science education during the last three decades (e.g., Gess-Newsome, 1999; Hashweh, 2005; Lee & Luft, 2008; Loughran et al., 2001; Magnusson et al., 1999; Park & Oliver, 2008), has provided a vision for understanding the professional knowledge teachers need in order to teach specific science content and practices. According to Shulman (1987), PCK "includes the most useful forms of representation of these ideas [the content to teach], the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9).

Despite the varying conceptions of PCK, there is a consensus that PCK develops as a result of the experience gained through teaching and addresses three dimensions of teachers' professional knowledge: (i) what a teacher knows, (ii) what a teacher does, and (iii) reasons for a teacher's action (Baxter & Lederman, 1999). Consequently, PCK is not merely teachers' knowing and understanding of effective science teaching; rather, it also includes successful enactment of science lessons in a classroom, thus adding practical value to the PCK construct. The development of PCK usually occurs when teachers experience a shift in their views and understanding of teaching science, which involves comprehension of subject matter knowledge in new ways to transform it into "metaphors, examples, demonstrations" (Shulman, 1987, p. 13) and curricular events (Carter, 1990) for a group of students. Park & Oliver (2008) claimed that the development of one component of PCK contributes to the development of other PCK components, and may enrich overall PCK. To follow a change in a science teachers' practice, it is crucial to observe and identify a change in individual PCK components in order to determine PCK development in each component.

This research borrows a definition of PCK (Kind, 2015) as personal knowledge of teachers that is located in their classroom practice and may develop as a result of implementation of an innovation in a science classroom. This specialized personal knowledge of teachers includes "understanding and enactment of how to help a group of students understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment" (Park & Oliver, 2008, p. 264).

To analyze the data collected in this study, the Park & Oliver (2008) conception of PCK is adopted, consisting of two dimensions: understanding and enactment. Teacher efficacy serves as a bridge between these two dimensions, and helps teachers enact their understanding in classroom settings. Consequently, successful enactment may result in increased teacher efficacy (Park & Oliver, 2008). These authors present PCK in a hexagonal model with PCK (understanding and enactment) at the centre and six sub-knowledge components on each of the six corners: (a) orientation to teaching science, (b) knowledge of science curriculum, (c) knowledge of students' understanding in science, (e) knowledge of assessment of science learning, (e) knowledge of instructional strategies for teaching science, and (f) teacher efficacy (refer to Fig. 1). The following provides a brief description of each of these PCK components:

- Orientation to teaching science

Orientation to teaching science refers to teachers' beliefs about the purposes of teaching science at a particular grade level. Teachers' orientations to teaching science may play a significant role in the development and shaping of their PCK. Park & Oliver (2008) categorized these orientations into three sub-categories: (i) beliefs about purposes of learning science, (ii) beliefs about the nature of science, and (iii) decision-making in teaching.

- Knowledge of science curriculum

This PCK component focuses on teachers' understanding of the science curriculum, particularly as it relates to a specific science area or topic, but also includes teachers' ability to recognize horizontal and vertical curriculum links. According to Park & Oliver (2008), "This component is indicative of teacher understanding of the importance of topics relative to the curriculum as a whole. This knowledge enables teachers to identify core concepts, modify activities, and eliminate aspects judged to be peripheral to the targeted conceptual understandings" (p. 266). Some scholars also refer to this component as curriculum saliency (Geddis et al., 1993).

- Knowledge of students' understanding in science

Knowing students' understanding of science is critical for teachers to employ PCK effectively. This aspect of PCK emphasizes that teachers should have knowledge about what students know about a science topic and potential areas of difficulty in learning this science topic. More broadly, "knowledge of students' conceptions of particular topics, learning difficulties, motivation, and diversity in ability . . . interest, developmental level, and need" (Park & Oliver, 2008, p. 266) are components of this PCK aspect.

- Knowledge of assessment of science learning

Knowledge of assessment is an important component of science teachers' PCK. Teacher knowledge of assessment consists of two parts: (a) what aspects of a science topic should be assessed and (b) what methods or measures are best used to assess them (Tamir, 1988). Magnusson et al. (1999) also used the following two categories to elaborate on this aspect of science teachers' PCK: (1) methods of assessing science learning and (2) dimensions of science learning to assess.

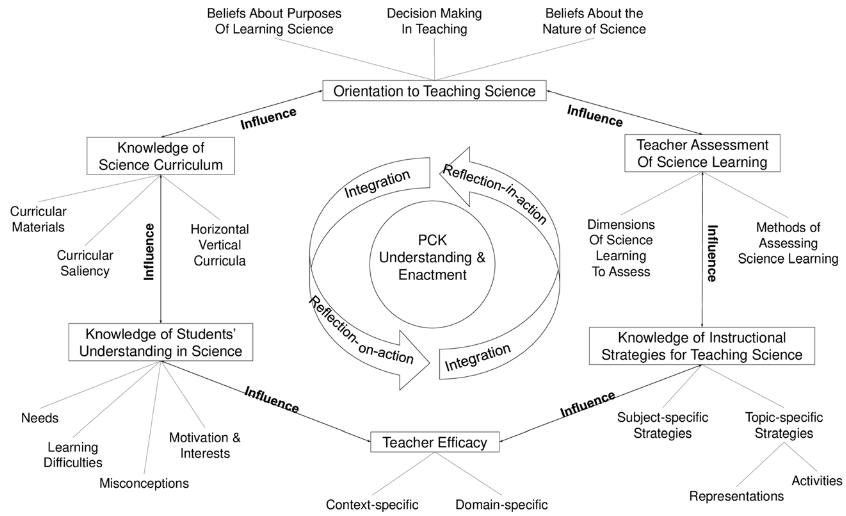

Fig. 1 Hexagon model of pedagogical content knowledge for science teaching (Park & Oliver, 2008)

- Knowledge of instructional strategies for teaching science

Knowledge of instructional strategies includes subject-specific and topic-specific strategies for teaching science. Subject-specific strategies are general approaches to science teaching that are aligned with the goals of science, such as addressing and modifying alternative ideas (conceptual change) and implementing inquiry-oriented instruction. Topic-specific strategies include particular techniques used to clarify and explain specific science topics and concepts within a domain of science.

- Teacher Efficacy

Teacher efficacy refers to a teacher's judgement of their ability to help students learn (Bandura, 1997). Teachers who have strong self-efficacy beliefs (i) display greater planning and organization skills, (ii) are open to new ideas, and (iii) are ready to experiment with new instructional strategies to foster deeper learning of their students (Jerald, 2007). Strong self-efficacy beliefs help teachers be persistent and not give up when things do not go as planned in the classroom. Park & Oliver (2008) introduced teacher efficacy as a new PCK component and considered this concept as a form of personal knowledge, which connects professional understanding and enactment in classrooms.

PCK "encompasses both teachers' understanding and enactment" (p. 263), thus showing the relationship between teachers' knowledge and their classroom practice as they adopt an innovation such as drone technology (Barendsen & Henze, 2017). Carlson & Daehler (2019) further expound on this notion of enacted PCK, referring to it as a model that "applies to the knowledge of and reasoning behind the act of teaching when interacting directly with students (reflection in action), … [and] also to the acts of planning instruction and reflecting on instruction and student outcomes (reflection on action)" (p. 84). The above six components influence teachers' PCK in a "contextually bound way" (Park & Oliver, 2008, p. 280), causing effective science teaching to occur when these six components integrate in a given context of classroom teaching.

Research Questions

To gain insight into teachers' developing PCK and its enactment, the authors collected data to address the following research questions: (a) How do components of teachers' PCK change as they adopt drone technology in the context of a unit on habitats? (b) What challenges will the teachers encounter as they adopt inquiry-based approaches to teaching and learning using drone technology? and (c) What factors will influence the development of teachers' PCK?

This study contributes to a growing body of literature that examines teacher PCK development as it relates to inquiry-based learning (Dogan et al., 2016; Lee, 2011; Smit et al., 2017). In addition, it will contribute to an understanding of the challenges teachers encounter when they adopt new technologies such as drone technology in science.

Methodology

While collaborative action research was utilized by the teachers to engage in teacher inquiry, the authors adopted case study (Merriam & Tisdell, 2015) to document the development of elements of the teachers' PCK as they integrated drone technology into their science teaching practice. Case study is useful in complex contexts such as classrooms (Taber, 2013) where researchers are asking *how* and *why* questions without controlling behavioural events (Merriam, 1998; Yin, 2014). A case study is an intensive, holistic, descriptive qualitative analysis of a "single unit or bounded system" (Merriam, 1998, p 12). This case study allowed the researchers to develop an in-depth understanding of how the adoption of drone technology influences teaching. The examination of the teachers' developing PCK over time employed a variety of data sources and methods, including the following:

1. Interviews (I)

Each teacher was interviewed for approximately 1 hour at the end of the project; the interviews were later transcribed. Interview questions were developed around the elements of PCK, as outlined in the Park & Oliver (2008) model, focused on both teacher understanding and classroom enactment. Example questions were as follows: "How did your beliefs about student learning change during the project? and How did you engage students in learning through inquiry?" Also, informal interviews occurred, based on informal conversations during school visits and planning sessions. Notes were recorded based on these conversations.

2. Reflections (R)

The teachers each completed 6–8 reflections (200 to 500 words each) during the planning and implementation stages of their project. The reflections offered the teachers an opportunity to document their planning, reflect on their changing beliefs and understandings, and describe how their classroom practice was evolving in relation to student learning.

3. Artifacts (A)

Documents created by the teachers, such as lesson plans, activities, and assessment tools, were a source of data. Also, to document their students' learning as they engaged in collaborative action research, the teachers collected classroom data such as classroom artifacts (e.g., pictures, classroom notes, student assignments and projects, videos). In total, the teachers created over 100 artifacts. These were examined by the authors to corroborate research themes. Another source of data was a multi-media presentation (text, pictures, video, audio) created by the teachers at the end of the action research cycle. Notes were recorded based on an examination of this artifact.

4. Observations (O)

Five visits (in-school and during field trips) were made by one of the authors as teachers implemented their projects. Each visit ranged from 45 to 120 minutes. Notes were recorded during these visits, based on what the teachers were saying and doing. These notes were compared with teacher-generated documents to determine fidelity between the different sources of data.

Data Analysis

All data sources were aggregated into one file, with all text being read and re-read by the three authors. Memos were recorded and shared amongst the researchers before more intensive data analysis occurred. For example, in one memo, the first author noted: "It seems the teachers experienced some degree of growth in areas of the [PCK] model." The first level of coding was completed by the third author using the six categories of the Oliver and Park model (2008). A second round of coding involved creating subcategories within each larger category (e.g., knowledge of science curriculum resources, learning outcomes). All authors reviewed categories, subcategories, and coded segments, reaching consensus on the nature of the coding (refer to Table 1).

To ensure the trustworthiness of the outcomes, the authors held ongoing debriefing meetings with the teachers about their unfolding understanding of their practice. Triangulation also contributed to the rigour of the study as multiple methods/sources of data were used to corroborate research findings (Maxwell, 2012). This study was approved by the ethics review board of the university, and teachers were introduced to ethics as it relates to studying one's own practice through action research.

Table 1 Data analysis: codes and sub-codes

Broad category	Sub-categories
Orientation to teaching science	Purposes for teaching science
	Decision-making
Knowledge of science curriculum	Curriculum outcomes
	Curriculum resources
	Content knowledge habitats
Knowledge of students' understanding in science	Student motivation
	Student diversity
	Student supports
Knowledge of assessment of science learning	Methods of assessment
	Dimensions of assessment
Knowledge of instructional strategies for teaching science	General strategies
	Specific science strategies
Teacher efficacy	Factors influencing teacher efficacy (e.g., time, feedback from students)

Context of the Study

Lois and Sam held minors in science and had 4-year undergraduate degrees in education. Lois was completing a graduate degree (curriculum, teaching, and learning) during the study, and Sam had an undergraduate degree in special education and a graduate degree in curriculum, teaching, and learning. Lois and Sam had taught multiple grade levels during their careers, with Lois having 10 years of teaching experience and Sam 8 years. The teachers worked in a public primary/elementary school with approximately 30 staff and 500 students. Lois described her 18 grade 4 students as heterogeneous in terms of ability, having "two who excel in math and reading …a couple of English as a Second Language learners and five receiving extra support outside the regular classroom in reading" (R). Sam described his 21 grade 4 students as having "diverse needs; two are gifted, and five have autism" (R). During the project, the teachers completed one cycle of collaborative action research starting in September and finishing in June and engaged in cycles of planning, acting, observing, and reflecting (Kemmis & McTaggart, 2005).

Lois and Sam were part of Teachers in Action, a 5-year initiative focused on K-9 teachers' professional learning in STEM action research. The focus for each action research project was determined by the teachers. Lois and Sam explored drones because they viewed this technology as a means to enhance student critical thinking and as a tool that could address curriculum outcomes in a habitat unit. They received 7 days of release time during the project, as well as a small budget for classroom resources. The authors offered support to the teachers in various ways: attending teachers' planning and debriefing meetings, offering feedback, acting as a sounding board, securing resources, and assisting with all aspects of the action research process.

While planning for their action research project, the teachers focused on knowledge outcomes in a unit on habitats and a variety of skills-based outcomes (refer to the Appendix for a list of these outcomes). The teachers' action research questions examined how the use of an inquiry-based approach to learning using drones could be used to enhance student engagement in learning science. Throughout the unit, the teachers and students used a software program called *Mission Planner* to plan routes for drone flights so they could collect data related to local habitats. Each of the three drones was a multirotor having four rotors arranged in a square pattern. The data took the form of two videos, recorded by the drones, and was later viewed by students when examining the nature of the local habitat. Examples of learning activities adopted by the teachers included (a) participating in an initial exploratory activity to ascertain what students already knew about drones, (b) administering an end-of-unit survey to determine what the students had understood in relation to knowledge outcomes and how they felt about the unit, (c) locating geographic locations and planning flight paths for the drones, (d) reviewing and analyzing video data collected by the drones of the local habitat (e.g., coniferous forest and bogs), (e) implementing a culminating activity where students were provided with pictures of a habitat and had to design and create plants and animals that would live in this habitat. This highlighted the basic needs of the organisms and possible adaptations they might have to survive in the habitat.

Prior to using the *Mission Planner* program and introducing the drones to students, the teachers, with the support of a local engineer (also a parent), assembled the drones from scratch and developed an understanding of how to program and fly the drones. Three large drones were used, as well as pre-assembled smaller drones. Students were gradually introduced to the drone technology and the smaller drones before planning two longer flights for the larger drones to collect data about local habitats.

Outcomes

The changes in teachers' PCK, based on the six components of the Park and Oliver model (2008), are reported on subsequently (refer to Fig. 1 as well). While each constitutes a separate subtheme for the purposes of articulating teacher professional growth, it should be noted that the six components interact in complex ways to influence teachers' PCK. Each teacher experienced changes in the six components, although the authors did not measure the degree of this change.

Orientations to Teaching Science

Teachers' orientations towards teaching science did not shift considerably throughout the study. Early in the study, the teachers reflected on their beliefs. They wanted to create science learning environments that were "student-centred, allowing students to explore and make sense of things themselves through discovery and inquiry" (Lois, R). During planning and implementation, the teachers shared explicit examples of their beliefs about the purposes of learning science and their decision-making in adopting drones to foster students' engagement. For example, while flying the drones to collect ecological data, one of the drones was lost. Surprisingly, the teachers' chose to use the mistake as a source of learning, as reflected in the comments of Lois: "Be open to errors and discovery that may take a different path than predicted" (A-Multimedia notes). Both teachers described the importance of the drone loss as a problem that required an explanation. The teachers required their students to conduct an analysis of the situation and to offer possible explanations for the loss, far removed from learning focused simply on knowledge and comprehension. The decision supports their initial "purposes of learning science" as represented in comments such as "student outcomes should [focus on]…problem solving and hands on learning" (Lois, R) and allows for "students to actively participate in their own learning by doing hands-on activities which are meaningful and authentic" (Sam, A).

The explicit understanding of the concept of the nature of science was not evidenced in either teacher's comments or practice. However, Sam demonstrated an implicit understanding of the nature of science during the study evidenced by these statements: "I am glad that [the students] were able to see and talk with people [(drone experts)] who work with drones in everyday life" (I).

Knowledge of Science Curriculum

The adoption of drone technology created a novel context for the application and then expansion of the teachers' knowledge of the science curriculum. However, before this occurred, both teachers demonstrated a concern for time and resources required for addressing curriculum outcomes. Sam stated the need to "get all of the drone parts in our school building and organize a planning day with our 'drone expert' to review the parts and assemble one together" (R).

The use of drone technology fostered the teachers' curriculum saliency towards a new focus on skills outcomes and making more explicit connections between knowledge and skills outcomes. While the teachers had been aware of the importance of emphasizing skills and processes in science, it had not been translated significantly or regularly into their classroom practice. Lois stated during the interview: "I was familiar with the content outcomes in my curriculum guides, but I now have a better understanding of the skills outcomes, focusing on them more directly." Likewise, Sam initially focused on content goals fairly heavily prior to starting the project. With a new focus as part of this inquiry, he "wanted the students to be able to build and create the drones and then use the drones . . . information in our footage or data for the use of habitat and rocks and minerals" (R). He realized the significance of skills as a focus of instruction:

> …my focus was on the "content" area of the curriculum outcomes, even though it probably only accounts for 25% of the outcomes per unit. However, through this [inquiry] process, I have spent much more time on developing the 'skills' component of the curriculum which accounts for approximately the remaining 75%. (I)

The use of drone technology expanded the teachers' integration of this tool within their habitat unit and resulted in teacher learning and changes in their classroom practice.

Knowledge of Students' Understanding in Science

While engaged in their action research project, the teachers developed an understanding of (i) the process of science learning, (ii) students' learning needs, and (iii) ways to motivate their science learners.

Lois described her understanding about the idiosyncratic process of learning. She said, "I found that using this project I have a better understanding of how different students learn and how this approach gives all students the opportunity to participate and learn at their pace" (R). Sam also acknowledged that "not all students will learn the same way," and showed a commitment to support student learning by modifying and adjusting his teaching and assessment practices (R). Lois and Sam also recognized the particular learning needs of the diverse learners in their classrooms. According to Lois: "I have a small but diverse group; this project helped me understand how they learn and how they process new information . . . . there are a few students that need much more one-on-one time and ESL support" (I). Describing her efforts to support diverse learners, Lois noted in a presentation: "I then structure my classroom around their needs and how to help the students get the most from this learning environment" (A). Also, Sam acknowledged the range of abilities that his learners brought to his classroom. He further explained his understanding of how to engage the varied abilities of his students: "All activities were tiered so that all my students were engaged at a level that worked for them and their learning style" (I).

Both Lois and Sam were able to identify and address their students' learning needs, particularly their needs related to learning drone technology, as many of their students were using drones for the first time. So, before they assigned the project of searching local habitats, they wanted to make sure each of their students was comfortable using drones and had gained some expertise with flying drones. Lois described their goal to help students learn drone technology: "We wanted [students] to be able to learn the software [*Mission Planner*], which was part of the technology [(drone)] that we used . . . . [Therefore] we went through *Mission Planner* with them again and taught them how to actually create a flight plan" (I).

Sam and Lois held a shared focus on motivating their learners to engage with the drone technology, which required support and encouragement for their students. Sam described his effort to provide a safe and welcoming environment, "to ensure they walk into a classroom where they feel welcomed, respected and appreciated each day" (O). Lois explained the process of readiness, where she gradually supported students to use drone technology, particularly learning new software (*Mission Planner*). However, they "did give kids the chance to explore Mission Planner" and according to Lois, "the actual hands-on part surprised us" (I). Sam was also amazed by fourth graders' engagement with Mission Planner, and noted: "Students were able to go on their individual computers and plot their waypoints . . . which are points that you wanted the drone to follow, and the kids were able to do that, once I showed them" (I).

The adoption of other forms of technology such as robots, rather than drones, may have also resulted in similar changes in the teachers' understanding of student learning. However, in this instance, the drone technology was used as a tool to target particular learning outcomes and to create inquiry-based learning environments that encouraged students to become more responsible and self-directed in their learning. In order to support student learning through inquiry, teachers explicitly examined aspects of their PCK and how they were being engaged and developed as they conceptualized and implemented their research project.

Knowledge of Assessment of Student Learning

While both teachers, at the beginning of the study, were aware of and familiar with a broad range of assessment approaches, they referred to their assessment in science as "aligning with more traditional approaches such as quizzes, assignments, and projects" (Lois, R). Describing her understanding of assessment, Lois clarified that she was never a "test person" who relied heavily on "paper-and-pencil" tests, but she considered her practice of assessment as narrow in scope.

During the inquiry, Lois and Sam experienced a shift in their understanding of assessment of science learning. They used new tools in science such as classroom observations and videos, to collect better evidence of student learning:

> We sat down and we just talked about . . . . our research questions, [and discussed] how will we know [the learning of our students]? . . . . We could do a paper and pencil test, but [we decided] to use chatting with kids in the classroom or watching some of the videos that we took of [students]. (Sam, I)

In the words of Lois: "Now, I am using things [such as] anecdotal notes, observations of students, conversations [with individual] students, or conversations with small groups" (I).

What to assess Lois and Sam acknowledged the possibilities of assessing skills along with science content, which, for them, was a new dimension of assessing student learning. They also concentrated on assessing "what they are doing" and not just on what they are learning (O). This was a shift that was directly related to their engagement with drone technologies and in action research.

How to assess While revealing the what to assess, Lois and Sam also emphasized the notion of individual difference in relation to learning pace and its import for adopting diverse means of assessment of science learning. They assessed students using a variety of data collection methods, such as "surveys, student-created work, observations, videos, and pictures" (Lois, R), and "checklists . . . followed by an exit card, or independent activity" (Sam, R). The multitude of assessment methods "allowed the teachers to have more opportunity for observations and conversations" (Lois, A).

Knowledge of Instructional Strategies for Teaching Science

Lois and Sam experienced growth in their knowledge of instructional strategies, which was evident from their use of subject-specific, topic-specific, and technology-specific (drone) strategies. They participated in professional development about inquiry-oriented learning and teaching. They were exposed to readings about 5E instructional cycle (see Bybee et al., 2006) and had the opportunity to "have discussions about the various steps involved" (Lois, R). The idea of the 5E learning cycle was new to Sam, and he needed to get his "mind wrapped around the idea of the cycle" before he implemented it in his classroom: "I have read articles, and I do know the main idea of the model but to effectively introduce it into my own classroom will still take a little time for me" (R). Later, Sam reported using the 5E model for his day-to-day instruction during the unit. One significant change he described was getting away from telling students the answers and focusing on finding ways to help students make their own inferences and draw conclusions:

> You don't tell them the answers or don't be afraid to teach them to start off with a question that you are not sure about yourself. . . . . And just like having them exploring and actively participating in their own learning. . . . So, just having them think about all the scenarios, all the possibilities. (Sam, I)

Lois appeared more comfortable with the idea of the 5E instructional cycle as she was already implementing some aspects of it in her classroom. However, she acknowledged the need to practice it: "I am hoping to become more comfortable with teaching problem solving/inquiry-based learning especially using the 5E model." Lois described the changes she noticed in her teaching: "Now my science lessons usually begin with some kind of introduction question or activities. . . . [and] when they have completed the activity I bring them back for a group discussion about what we are learning" (R). She also observed that she poses more questions to students and gives them more ownership during experiments.

Teacher Efficacy and Other Factors Influencing the Development of Teachers' PCK

Several interrelated factors contributed to the development of the teachers' PCK. Having time through the professional development program to systematically plan, read literature related to drones and teaching through inquiry, collect data to inform their understanding of their classroom practice, and share regularly during implementation were important factors contributing to the teachers' evolving PCK. Reading general information about drones and how they may be adopted to enhance student learning positioned the teachers to be more informed when making decisions about how to incorporate the drones into the curriculum.

Collecting and generating teacher data or evidence such as student work, photographs, and ongoing journal reflections allowed the teachers to examine their classroom practices and student learning systematically. Reviewing the data informed decision-making regarding how to support student learning as the teachers were adopting inquiry-based approaches to teaching and learning using drones.

They completed written individual and collaborative reflections throughout their project, making their thinking explicit. Often, they would revisit previous reflections and return to the data regularly to collaboratively examine their emerging findings. Both Lois and Sam identified that having designated time to work collaboratively was critical to their success and enabled them to make changes as they gained more insight into student learning. They also noted: "Using these tools [reflection and systematic inquiry] allowed us to see what we wanted the students to understand; this helped with evaluating our research question and supporting student learning" (R).

Two other highly connected factors that contributed to PCK growth and changes in their classroom practice were knowledge of student learning and teacher efficacy. As the teachers gained more insight into how to support student learning through the adoption of drones and inquiry-based approaches to teaching and learning, they strengthened their confidence and belief in their own ability to create a classroom learning environment that could engage all learners. As they received more positive feedback from their students, they slowly became more comfortable with inquiry and using the drone technology to target science outcomes. Sam commented in the interview: "This has opened my eyes. I always knew, in my head, that I could use student-centred approaches. I feel better as a teacher."

This enhanced self-efficacy occurred in the context of engaging in teacher-directed professional learning; receiving support from the research team, other community individuals and organizations, and the school-based leadership team; and having time to engage in professional learning.

Challenges in Adopting Drone Technology

The teachers experienced several challenges in adopting the drone technology. Initially, when exploring the idea of using drone technology to enhance their science curriculum, the teachers considered using pre-made drones or drone kits. They decided not to do this. Instead, they worked closely with a parent volunteer, an engineer who had considerable expertise in building and flying drones, and with his guidance built large drones from scratch. While they reported learning a lot about the construction, maintenance, and flight of drones, they never became totally comfortable with using and repairing the drones. At one point, later in the implementation phase of their project, Sam noted: "We had to overcome a few problems…we would have never gotten the drones off the ground without the help of our parent volunteer. We were a little too dependent on him" (I). In retrospect, Lois and Sam would have approached the project differently, as Sam shared during a school visit: "If we had been more familiar, I would have chosen to build smaller drones and maybe purchased some of the smaller ones [kits] to allow the students more direct involvement with the technology itself" (O). Initially, the teachers decided they would have students build the drones. Once they started the process of building one themselves, they concluded it would be too time-consuming and complex for students to take on this task. Also, the teachers wanted the experience of building the drones themselves, rather than simply purchasing pre-made drone kits, to enhance their knowledge of drone construction and flying.

Other unanticipated challenges arose as the teachers planned their first drone outing with the children. A new law was introduced that prevented the use of drones within a 9-km radius of an airport tower and over people. This meant the teachers had to find a location outside the city, which also necessitated bus transportation and more funding. They were, fortunately, able to secure more funding to allow for several outings to fly the drones. Also, after contacting a local flying club, who held a special permit to use drones, they were invited to use their space and resources for a couple of school outings.

Discussion

It was evident from this study that two aspects of the teachers' orientations (the purposes of teaching science and decision-making in teaching) influenced their planning and classroom practice. Because they believed that learning in science should offer students authentic, hands-on experiences that encourage problem-solving, they immersed their students in real-world learning by having them plan flight paths for drones and collect data about habitats. In order to create a learning environment that was student-centred and inquiry-based, the teachers adopted a new instructional approach to fostering inquiry (the 5E cycle) and expanded their assessment repertoire to target skills-based outcomes. This alignment of orientations and other elements of PCK has been demonstrated in other studies (e.g., Boesdorfer, 2015; Campbell et al., 2017; Demirdöğen & Uzuntiryaki-Kondakçı, 2016; Sahingoz, 2017; Wei & Liu, 2018). Moreover, many PCK scholars have identified orientations as a key component of PCK and discussed its essential role in the enactment of PCK (Abell, 2008; Friedrichsen et al., 2011; Gess-Newsome, 2015; Park & Chen, 2012).

The relationship between orientations and other PCK components suggests that teachers need to make their orientations explicit and reflect critically on how these orientations may impact their decision-making as it relates to curricular emphases and choice of instruction and assessment approaches. It should be noted that orientations are not unidimensional and that teachers' orientations are often multi-faceted (Friedrichsen et al., 2011; Magnusson et al., 1999).

Studies in which teachers have adopted drone technology are limited, especially regarding how teachers' PCK becomes engaged and transformed in science classrooms. However, the use of drones within curriculum is spreading within the USA and Australia (Gillani & Gillani, 2015; Sattar et al., 2017). Smith & Mader (2018) suggest that drones can "be an exciting learning tool" (p. 16). Yet, within an elementary school setting, there are currently no published studies of students using drones to address curricular outcomes. Teachers within this study used drones as tools to study ecosystems, a practice that is increasingly used by field biologists to study habitat composition and populations, such as elephants (Schiffman, 2014).

Drones may also be adopted to foster tinkering, a "branch of making that emphasizes creative, improvisational problem solving. It centers on the open-ended design and construction of objects or installations, generally using both high- and low- tech" (Bevan et al., 2015, p. 99). Teachers, when adopting drone technology, need to consider their purposes for incorporating drones into the curriculum and how drones may be used to foster an understanding of scientific practices and the nature of science (Wagh et al., 2017).

While the focus of this study was not to ascertain the degree to which components of teachers' PCK became integrated or the degree of change in each component, this research does illustrate that the integration of PCK components is complex and contextual factors influence how PCK components become engaged in practice (Aydin & Boz, 2013; Park & Chen, 2012). These contextual factors, such as changes in teacher efficacy and having access to effective professional learning, need to be considered carefully when teachers are adopting innovations and new technologies. This raises the issue of the idiosyncratic nature of PCK. It can be assumed that other educators may learn from the experiences described here; however, the adoption of drone technology using an inquiry-based framework will certainly vary from teacher to teacher. This study provides insight into one possible way elementary teachers may use drones as a tool to promote inquiry-based teaching and learning in science.

Based on the outcomes of this study, the authors offer recommendations for researchers, those who support teacher professional learning, and teachers who are transitioning to the adoption of various approaches to inquiry-based teaching and learning using new technologies, including the following:

1. PCK should be used as an explicit framework when adopting inquiry as a form of teaching and learning in the context of science education. PCK is an academic construct, but has the potential to help teachers make their tacit thinking explicit. As other researchers have shown (Cross, 2009; DiBiase & McDonald, 2015; Wong & Luft, 2015), teacher's orientations towards student learning are often resistant to change. By using the PCK framework as a reflective tool, teachers may be better positioned to understand their own strengths, limitations, and readiness as it relates to inquiry adoption.
2. Teachers' readiness to shift from teacher-focused learning environments in science to more student-focused environments needs to be considered when designing and supporting teacher professional learning. Considerable research has shown that the adoption of inquiry by teachers is time-consuming and messy, requires the development of particular ways of thinking and skills to manage and support student learning through inquiry, and necessitates relinquishment of classroom control (Goodnough, 2016; Chichekian et al., 2016). Consequently, teachers' starting orientations and current classroom practices need to be documented and examined, with primary input from teachers themselves about their needs.
3. When adopting a new technology as a tool to support inquiry-based teaching and learning in science, careful consideration should be given to the nature of the particular technology and its pedagogical potential (strengths and limitations) for addressing both teacher and student needs and curriculum learning outcomes. However, this consideration needs to occur in a context that offers teachers both technical and pedagogical support and has school-based leadership teams that prioritize the adoption of technology (Henderson & Romeo, 2015; Shattuck, 2010).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Appendix. Curriculum outcomes targeted when adopting drone technology in the context of a unit on habitats

Knowledge

Identify a variety of local and regional habitats and their associated populations of plants and animals.
Investigate and describe how a variety of local animals are able to meet their basic needs in their habitat.
Compare the structural adaptations of plants that enable them to thrive in different kinds of places.

Skills

Identify various methods for finding answers to questions and solutions to problems, and select one that is appropriate.
Make observations and collect information that is relevant to the question or problem.
Identify and use a variety of sources and technologies to gather relevant information.
Compile and display data.
Identify and suggest explanations for patterns and discrepancies in data.

Draw a conclusion that answers an initial question.
Suggest improvements to a design or constructed object.
Communicate questions, ideas, and intentions, and listen to others while conducting investigations.

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