High School Science Teacher Remote Lesson Study: Growth of Pedagogical Content Knowledge, Development of Remote Science Inquiry Instruction, and Second-Generation Activity Theory Analysis of Mediation and Expansive Learning

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Contents

List of Abbreviations

CHAT - Cultural-historical Activity Theory

CMEC - Council of Ministers of Education, Canada

LS – Lesson Study

NLESD - Newfoundland and Labrador English School District

NLDE - Newfoundland and Labrador Department of Education

PCSC - Pan-Canadian Science Curriculum

PCK – Pedagogical Content Knowledge

PL – Professional Learning

RCM - Refined Consensus Model of PCK

Glossary

CHAT, Cultural Historical Activity Theory – CHAT examines how a Subject, such as a group of teachers, conducts actions within the activity towards an Object. For example, for a teacher (subject) instructing students (activity), the instruction of a lesson is a goal-directed action toward the Object (student learning). Within the lesson, conditions may dictate changes to a demonstration for certain students – the demonstration and the subsequent condition-related changes are termed operations.

cPCK, Collective Pedagogical Content Knowledge – Knowledge that is "an amalgam for multiple science educator's contributions including the teachers' own contributions" and includes knowledge bases that can be shared and is considered public (Carlson et al., 2019, p. 90)

ePCK, Enacted Pedagogical Content Knowledge - The knowledge used in the practice of teaching "is the specific knowledge and skills utilized by an individual teacher in a particular setting, with a particular student or group of students, with the goal for those students to learn a particular concept, collection of concepts, or a particular aspect of the discipline." (p. 85)

KO, Knowledgeable Other – A lesson study supporter, generally a subject specialist who can coach teachers by offering content and pedagogical support. A KO will often observe the research lesson and offer critical comments.

LS, Lesson Study - Lesson Study is a century-old form of teacher research that has spread widely from mathematics to many subjects. During LS, the teachers or lesson study group develop a research lesson using an iterative four-step cyclical to study the research lesson: (1) studying the curriculum and formulating goals, (2) planning the lesson, (3) conducting the research lesson for others, and (4) reflecting on and consolidating learning and for another LS group member to present the same or modified lesson to repeat steps 3 and 4 (Lewis et al., 2006; Lawrence & Chong, 2010; Cheung & Wong, 2014).

Lesson Study Group - The teachers who develop and teach the research lesson.

Mediation and Mediating Artifacts - Teaching is an activity mediated by artifacts such as diagrams, video instructions, and texts (see Tools). These artifacts mediate teaching and learning by the student as socially shared cognitive and physical resources (see Tools).

PCK, Pedagogical Content Knowledge - Shulman conceptualized the knowledge required for teaching science (1987, p. 9) "beyond [the] knowledge of subject matter per se to the dimension of subject matter knowledge for teaching." This has evolved to multiple contextual definitions in the refined consensus model of PCK (Carlson et al., 2019; see - ePCK, pPCK and cPCK).

pPCK, Personal Pedagogical Content Knowledge – a teacher's knowledge, their cumulative reservoir of learned PCK that can be used as ePCK (as teaching or planning) and pPCK that may be filtered or amplified through pedagogical reasoning (Carlson et al., 2019).

Student Inquiry in Science or Inquiry – inquiry is a term that refers to three distinct categories of learning activities: what scientists do, how students learn, and the pedagogical approach by teachers (Minner, 2010). During inquiry science instruction, students investigate questions that may take several forms: confirmation, structured, guided, and open inquiry. For example, a lab that reinforces a well-known phenomenon using a demonstration is considered a confirmation inquiry. However, in an open inquiry, the students develop the questions and experimental design and then provide a solution (Banchi & Bell, 2008).

Tools - Technological instruments are tools but are different from psychological tools. This study defines a computer as an instrument (Vygotsky, 1978), while hypermedia and graphical applications are psychological tools as they directly support learning. Geist (2008) sees the computer programs or interactive simulations used to visualize digitalized material as psychological tools.

Zone of Proximal Development - Vygotsky (1978) conceptualized the zone of proximal development as "the distance between the actual developmental level is determined by independent problem-solving, and the level of potential development is determined through problem-solving under adult guidance or in collaboration with more capable peers" (p. 86).

Chapter 1 - Introduction and Literature Review

This thesis presents three unique lesson study manuscripts. Chapter 2 is an analysis of teacher learning as PCK during lesson study (Carlson et al., 2019), Chapter 3 chronicles remote science inquiry instruction with students, resulting from the development of the lesson study research lesson, and Chapter 4 is a Cultural Historical Activity Theory or CHAT (Engstrom, 1987) analysis of the ontogeny, or development, of the research lesson. The subsequent introduction and literature review within this chapter will introduce lesson study (LS), pedagogical content knowledge (PCK), inquiry instruction, and CHAT to prepare readers for the technical details of the manuscript chapters. The common thread of these studies is LS teacher research, which is defined and then situated within a review of teacher professional learning. To start, I will contextualize inquiry instruction for science teaching and the science teachers of this investigation. After this, the theoretical perspectives of each of the three manuscripts will be introduced: the development of PCK, student science inquiry learning, and finally, CHAT.

Local Teacher Scientific Inquiry Skills and a New Curriculum

Over a century ago, John Dewey, a former science teacher, called for the use of the scientific method, or inquiry, as a response to excessive teaching of facts "without enough emphasis on science for thinking and attitude of the mind" (Barrow, 2006, p. 266). Dewey (1938) connected the sensory and personal experience of inquiry:

> I assume that amid all uncertainties there is one permanent frame of reference; namely, the organic connection between education and personal experience; or, that the new philosophy of education is committed to some kind of empirical and experimental

> philosophy. However, experience and experiment are not self-explanatory ideas. Rather their meaning is part of the problem to be explored. To know the meaning of empiricism we need to understand what experience is. (p. 25)

Science inquiry instruction, remote or face-to-face, seems to fit what Dewey would call the *new education,* and he contrasted this with traditional teaching:

> To imposition from above is opposed to expression and cultivation of individuality; to external discipline is opposed free activity; to learning from texts and teachers, learning to experience; to acquisition of isolated skills and techniques by drill, is opposed to acquisition of them as a means of attaining ends which make direct vital appeal. (p. 19)

During 28 years as a high school science teacher, I facilitated over ten professional learning sessions and was involved with three published teaching and learning projects (Goodnough, 2016; Wells, 2017; Wells et al., 2017). Early in my career, I was developing my skills to support students' technical inquiries. Aside from the science fair projects I helped with, much of my early inquiry work with students involved confirmation inquiry, where students confirm phenomena presented during instruction (Banchi & Bell, 2008). These experiences, especially with action research (Goodnough, 2016; Goodnough et al., 2019; Wells, 2017), revealed the challenges with scientific inquiry instruction and the process of conducting inquiry instruction with students.

New Curriculum

The long-standing Pan-Canadian Science Curriculum (PCSC) foundational statements, negotiated by the Council of Ministers of Education, Canada (CMEC), is the national guide for developing a curriculum for student scientific literacy, including (1) Science, technology, society, and the environment (STSE); (2) Skills; (3) Knowledge; and (4) Attitudes (CMEC, 1997). The Newfoundland and Labrador Department of Education (NLDE) new science curriculum used the PCSC framework to stress science inquiry when developing the Integrated Skills Unit (ISU). The ISU of the Science 1206 course (NLDE, 2018) includes science skills such as analyzing and interpreting that may be applied in various contexts and linked with scientific inquiry, problem-solving, and decision-making (CMEC, 1997). The 2018 Science 1206 Curriculum Guide states that while addressing curriculum outcomes of the new Integrated Skills Unit, "students will develop the skills required for scientific and technological inquiry, for solving problems, for communicating scientific ideas and results, for working collaboratively, and for making informed decisions" (NLDE, 2018, p. 29).

I was involved with the final stage of the ISU curriculum development where teachers who practiced activity-based instruction, were invited to review, and adjust the outcomes to guide teachers. In these sessions, while examining the ISU outcomes, I came to understand understood how they would guide teachers to conduct inquiry instruction where students would make predictions, then perform experiments to collect data to test their predictions. However, the ISU, and its 29 skill-related outcomes, represented an obvious shift toward using scientific practices and decisions making skills.

COVID-19 and remote research methods

This is an extraordinary addendum to any thesis introduction as the first challenge of this project was restrictions of the COVID-19 pandemic, an uncontrollable "run-away object" (Engeström, 2009). Before the pandemic, I intended to conduct LS face-to-face and visit classrooms. I had recruited 5 teachers from two separate schools and was set to conduct a multiple-case study. However, the NLESD response to the COVID-19 pandemic was to suspend all face-to-face classes on March 17, 2020 (Appendix 1). This action dictated the use of remote research methods (Appendix 2) and an amendment submission for the initial research ethics approval from the Interdisciplinary Committee on Ethics in Human Research (ICEHR) (Appendix 3). ICEHR approved the amendment for online protocols (Appendix 4), which required significant changes to the recruitment protocols, scripts, and letters (Appendix 5) to conform with the NLESD virtual protocols. Nevertheless, these adaptations for recruitment and conducting professional learning permitted the communication that would help address pre-pandemic science instruction issues.

Teacher Challenges of New Curriculum

Based on my previous experiences with PL, some teachers have experienced significant challenges addressing the ISU outcomes has many of these challenges have still not been addressed. Ample research evidence suggests that teachers who want to support student scientific inquiry benefit from long-term professional learning (PL) (Blanchard et al., 2013; Borko, 2004; Capps et al., 2012; Goodnough, 2010; Marshall et al., 2011; Miranda & Damico, 2015). However, effective professional learning is not simply a long-term commitment as many other vital features that contribute to in-service teacher learning have been described by multiple authors (Borko, 2004; Darling-Hammond et al., 2017; Guskey, 2003; Jeanpierre et al., 2005; Loucks-Horsley et al., 2012; McLaughlin, 1990). The subsequent section will review these features, then relate them to LS, the chosen form of teacher science inquiry PL used in this research.

Features of effective professional learning

Darling-Hammond et al. (2017) reviewed three decades of professional development literature and stated that effective professional learning "results in changes in teacher practises and improvements in student learning outcomes" (p. v). Guskey (2003) supports this focus on improved student outcomes as the goal of PD. Based upon their extensive work, Darling-Hammond et al. (2017) reported seven widely shared features of effective teacher professional development. Such development is:

1. Content focussed
2. Incorporates active learning
3. Supports collaboration
4. Uses models of effective practice
5. Provides coaching and expert support
6. Offers feedback and reflection
7. Of sustained duration (p. v-vi)

According to Jeanpierre et al. (2005), changing secondary teachers' practices to include more scientific inquiry involved PL with "content and numerous opportunities to experience the learning that they are expected to facilitate with students may serve to assist him in translating inquiry practices to their own classroom" (p. 686). From the science teacher literature perspective, Zhang et al. (2015) reviewed and reported similar consensus PL features for effective in-service science teachers:

> (1) informed by learning theories, (2) intensive, sustained and ongoing learning, (3) focus on content and curriculum, (4) opportunities for rich and active learning, (5) collaboration

> with other teachers, preferably from the same school, (6) connected to teachers' daily practice and their own learning goals, and (7) aligned with local, state, and national standards and objectives (p. 474).

In this study, Zhang et al. did not reference coaching and expert support, but did specify that same school collaboration is preferred.

In examining the long-term impact of the "Rand Change Agent Study" from the 1970's, McLaughlin (1990) noted that "Rand found that effective strategies promoted mutual adaptation, or the adaptation of a project and institutional setting to each other" (p. 12). Loucks-Horsley et al. (2012) believe local contexts should inform the PL process by addressing "issues that may influence to success and impact of any professional development, and plan ahead to address them" (p. 3). This holds for many PL projects, where the teachers in the local context must be involved as active participants and collaborators. This prevailing factor has been repeated in decades of teacher PL studies (Darling-Hammond et al., 2017).

My Science Professional Learning Experiences

My experiences with long-term science teacher action research in the Newfoundland and Labrador high school context echoes the finding that long-term PL, versus one-day workshops, for inquiry-based instruction supports science teacher learning (Goodnough, 2010, 2016; Goodnough et al., 2019; Wells, 2017; Wells et al., 2017). My action research experiences were largely independent, except for collaborative work with the Holy Spirit High School Science Department (Wells et al., 2017). Early in my doctoral studies, I was introduced to lesson study (Lewis et al., 2006; Lewis & Hurd, 2011). Despite a decade-plus of dedicated action research, Lesson Study (LS) was the teacher research used during my doctoral research. During my doctoral courses, I read *The Teaching Gap* and was impressed by LS's teacher research that was lesson-focused, structured, and focused on teaching, not the teacher (Stigler & Hiebert, 1999). In the subsequent section, I discuss how LS teacher PL has the seven widely shared features of effective teacher professional development reported by Darling-Hammond et al. (2017).

What is Lesson Study?

Lesson study, or *jugyou kenkyuu*, is a form of collaborative professional learning used by Japanese educators for over a century (Cheung & Wong, 2014; Stigler & Hiebert, 1999). LS arrived in North America in the late 1990s and was spread primarily through "The Teaching Gap" (Stigler & Hiebert, 1999) and other work by Lewis and Tsuchida (1997; 1998). These authors revealed the learning cycle structure (Figure 1) and LS's focus on teaching as opposed to teachers (Stigler & Hiebert, 1999). Since then, LS teacher research has spread widely from mathematics to many subject areas (Lewis et al., 2006; Cheung & Wong, 2014).

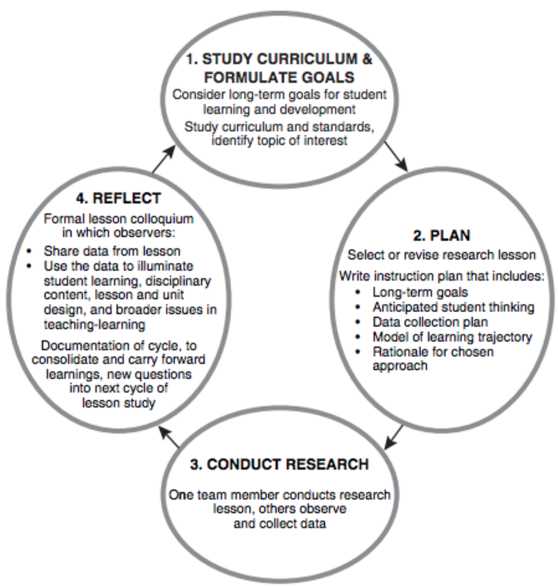

Figure 1 - The lesson study cycle from Lewis et al. 2006.

During LS, the teacher partners or groups first select a lesson that becomes the research lesson; this is one lesson that will be developed by the LS group guided by the cycle in Figure 1. A traditional LS uses an iterative four-step cyclical to study the research lesson: (1) studying the curriculum and formulating goals, (2) planning the lesson, (3) conducting the research lesson for others, and (4) reflecting on and consolidating learning and for another LS group member to present the same or modified lesson to repeat steps 3 and 4 of Figure 1 (Lewis et al., 2006; Lawrence & Chong, 2010; Cheung & Wong, 2014). Within the literature, however, LS shows variations in the number of cycles or rounds (Figure 1) of LS from 1 to 4, in teacher research time (from one day to a whole year), and the duration of the commitment to LS (from one year to many) (Cheung & Wong, 2014). How do these characteristics and their variability contribute to LS's popularity and effectiveness?

The rise in the PL status of LS may be attributed to LS's focus on teaching (Lewis et al., 2006), student learning (Dudley, 2013), and the collegial nature of sharing knowledge during lesson study cycles (Lewis et al., 2012). Lewis et al. (2012) reported that LS's focus on collaborative teaching contributes to collegial learning by connecting colleagues' practice and instructional resources. Dudley (2013) reported that LS improves microteaching, enhances understanding of students' learning needs, and improves student learning. Further, teachers who share learning goals through LS may become socialized into improving teaching (Hiebert & Stigler, 2017, p. 172). In traditional LS in Japan, often a knowledgeable other, such as a principal, subject expert, or university professor, may be a member of the LS group (Stigler & Hebert, 1999). In terms of the Darling-Hammond et al. (2017) seven widely shared features of effective teacher professional development, a knowledgeable other would be considered coaching and expert support. As outlined above, developing the LS research lesson requires a content focus, incorporates active learning during planning, supports collaboration with structure (Figure 1), uses models of effective practice, offers feedback and reflection and is of sustained duration (p. v-vi).

Examples of science teacher learning during lesson study

A recent review of LS literature indicates that few peer-reviewed studies examine changes in high school teacher learning during LS. Reviews by Schipper et al. (2018) and Lawrence and Chong (2010) found that LS positively impacted high school science teachers' self-efficacy. Schipper et al. (2018) also reported that LS promoted adaptive teaching required for the instruction of students of varied learning abilities using "differentiated lesson material or instructional strategies to address [the] learning needs and consequently prepare their lessons" (p. 115). Lucenario et al. (2016) reported increased high school science teacher pedagogical content knowledge (PCK) after LS experiences.

Two case studies have explored PCK changes in high school teachers during LS (Akerson et al., 2017; Lampley et al., 2018); Akerson et al. (2017) reported the impacts of LS on PCK on pre-service science teachers while Lampley et al. (2018) examined graduate teaching assistants. Akerson et al. (2017) used a modified version of the LS where the case was a subset of a cohort of pre-service teachers. The study examined PCK development for teaching the nature of science (NOS) over a four-week study period. The case's six pre-service teachers developed five LS lessons emphasizing NOS learning outcomes (Akerson et al., 2017). However, the results were inconclusive as the participants did not observe their peers or explicitly teach NOS. Also, their cooperating teacher needed to incorporate their ideas about

NOS (p. 308). The authors suggest using more explicit learning objectives to make these objectives a teaching target.

In a descriptive case study with multiple units of analysis, Lampley et al. (2018) used the five PCK components identified by Magnusson et al. (1999) as a framework for analysis. The case study included two lesson studies conducted over sixteen weeks and an analysis of multiple data sources, including participant written reflections, participant semi-structured interviews, classroom observations, participant field notes, research lesson plans, notes from an outside biology specialist, and researcher journal and field notes (Lampley et al., 2018). This study's most notable PCK result changed the participants orientations to science teaching and increased knowledge of instructional strategies.

Remote professional learning with lesson study

Lewis et al. (2006) reported that LS involves teachers sharing knowledge and reflecting, with the seminal goal of LS being the development, then teaching, of a research lesson. Lesson study is traditionally associated with face-to-face teacher PL for mathematics rather than science teacher PL (Hiebert & Stigler, 2017; Stigler & Hiebert, 1999). The COVID-19 pandemic changed the context for many LS groups and required a shift in how LS groups undertake their work (Calleja & Camilleri, 2021). Online or remote LS is a recent innovation – again predominantly practiced by math educators (Huang et al., 2021; Huang et al., 2023). Because the present study was conducted during the COVID-19 pandemic, the collaborative form of teacher research used was remote LS.

While research reports that face-to-face LS fosters the development of PCK (Allen et al., 2004; Dotger & McQuitty, 2014; Dudley, 2013; Lewis et al., 2006), remote LS researchers have reported varied results (Huang et al., 2021). Further, peer-reviewed research on LS with high school science teachers must be better represented in the literature. One suggested solution was to allow for “structured opportunities to engage in the implementation of those changes in thinking through reflection and the modelling and development of inquiry lessons” (Enderle et al., 2014, pp. 1103-4).

Literature Gaps for Remote Lesson Study

The deficiencies of the remote LS literature are magnified for science teachers as the expansion of remote LS is primarily focused on mathematics instruction (Huang et al., 2021; Huang et al., 2022; Huang et al., 2023). The LS cycle has lesson development components in common with the refined consensus model (RCM), namely, the Plan-Teach-Reflect within the teacher’s pedagogical reasoning (Carlson et al., 2019). However, none of the above studies of teacher knowledge have used the RCM to examine phase-by-phase teaching learning during face-to-face or remote lesson study. This investigation addresses two gaps in the literature specifically:

1. Science teacher lesson study in the remote context.
2. Science teacher learning during the phases of remote lesson study as characterized by the RCM, a widely accepted model of science PCK.

Literature Gap for Remote Instruction

Remote science instruction used in this study differs from virtual simulations (Price et al., 2019) and student remote manipulation of off-site experiments (de Jong et al., 2014). Few studies of LS exist for high school science – none that examine a science teacher’s online work for lesson development and synchronous student science inquiry. This research focused on the actions of the teachers and students during the remote inquiry and addresses a literature gap by documenting the details of an unreported form of instruction. Further, pandemic adaptations of the LS PL and teaching are new (Calleja & Camilleri, 2021; Huang et al., 2023) and require documentation. To address these gaps, two manuscripts were written; one focused on the form of instruction (RSII) and the other employed Cultural Historical Activity Theory (CHAT) to provide a holistic examination of lesson development that includes the influence of the students and other community factors. The gaps addressed are as follows:

1. Conducting science inquiry instruction is demanding face-to-face, and few reports examine remote science inquiry instruction (RSII).
2. CHAT (Engeström, 1987) has yet to be used to frame the development of a high school remote science inquiry lesson resulting from LS.

The subsequent literature review chapter will further demonstrate these literature gaps and prepare readers for the three manuscripts that follow; the analysis of teacher learning as PCK during LS (Carlson et al., 2019), remote science inquiry instruction (RSII), and the CHAT (Engeström, 1987) analysis of remote LS.

Literature Review

This literature review surveys the conceptual frameworks of the three manuscript chapters, Chapters 2, 3, and 4. Chapter 2 examines science teacher pedagogical content knowledge (Carlson et al., 2019; Shulman, 1986) during remote LS (Lewis et al., 2012), and thus, the PCK and LS literature require a review. The third Chapter manuscript is published in the *International Journal of E-learning and Distance Education* and documents remote science inquiry instruction (RSII), a newly reported form of science distance education instruction (Wells et al., 2022). To prepare readers for this chapter, I review the literature on high school science inquiry instruction to characterize science inquiry instruction and highlight the benefits and challenges of this form of science instruction in remote and face-to-face contexts. The final manuscript, Chapter 4, employs the lens of Activity Theory (Engeström, 1999) to analyze the activity, actions, and operations (Leont've, 1982) of all LS participants, their supporting community, and the students who participated in the RSII research lesson. The review begins by examining the science teacher PCK literature.

Pedagogical Content Knowledge (PCK)

Thirty-seven years ago, Shulman (1986, 1987) conceptualized PCK as a knowledge form possessed by teachers that separated them from subject specialists. During that time interval, a wave of teacher research presented categories of knowledge (Chan & Hume, 2019) and fashioned heuristic models to support modified PCK conceptualizations (Abell, 2008; Carlson et al., 2019; Gess-Newsome, 2015). Why did many researchers gravitate towards Shulman's "missing paradigm" of teacher knowledge? Perhaps it was Shulman's description of PCK as a transformative knowledge form, an "amalgam" of pedagogical and content knowledge (Shulman, 1987, p. 8). An attractive feature of Shulman's conceptualization was the clarification that a science teacher's knowledge "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (p. 9). A science teacher's knowledge includes "an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons” (Shulman, 1986, p.9). Shulman’s second PCK publication (1987) described four sources of knowledge that inform and develop PCK along with other teacher knowledge domains:

> (1) scholarship in content disciplines, (2) the materials and settings of the institutionalized educational process (for example, curricula, textbooks, school organizations and finance, and the structure of the teaching profession), (3) research on schooling, social organizations, human learning, teaching and development, and the other social and cultural phenomena that affect what teachers can do, and (4) the wisdom of practice itself. (p. 8)

The evolution of the definitions of teacher knowledge sources

A historical examination of teacher PCK and taxonomy of PCK knowledge sources and teacher characteristics, such as teacher beliefs (Magnusson et al., 1999), demonstrates a steady evolution from Shulman’s initial conception (1986) into the recent Refined Consensus Model for PCK (Carlson et al., 2019). In the next section I review the significant changes to PCK, starting with Grossman’s (1990) incorporation of teacher beliefs and then changes to knowledge bases and their organization. This is followed by a comparison of the changes to the most cited model of PCK, Magnusson et al. (1999), and the final research contributions that led to the Refined Consensus Model proposed by Carlson et al. (2019).

Grossman (1990) – domains and beliefs

PCK is a central component that informs and is informed by subject matter knowledge, knowledge of context and general pedagogical knowledge (Grossman, 1990). Pam Grossman located PCK in the middle of subject matter knowledge, general pedagogical knowledge, and knowledge of the context (Figure 2). Grossman’s (1990) definition of general pedagogical knowledge parallels Shulman’s PCK in many respects, with one significant difference, that being the acknowledgement of the importance of beliefs related to teaching and "beliefs concerning learners and learning" (p. 6). Beliefs, by definition, are from the affective domain of knowledge. Shulman admits he "did not devote attention to affect and motivation, nor moral judgement and reasoning in teaching" (2015, p. 9). The description of subject matter knowledge by Grossman strongly parallels Shulman's, who borrowed it from Schwab (1964), as "knowledge of the content of the subject area as well as knowledge of the substantive and syntactic structures" (Grossman, 1990, p. 6). Substantive discipline knowledge includes understanding paradigms and content organization, while syntactic knowledge involves knowing "the canons of evidence and proof within the discipline" (p.6).

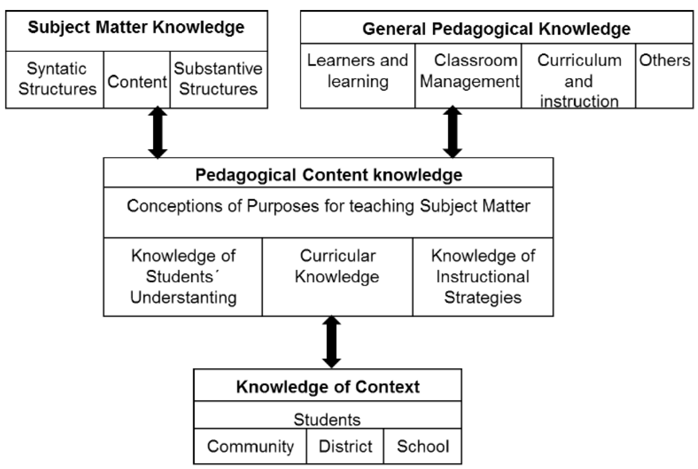

Figure 2. The four "cornerstones" of teacher knowledge, according to Grossman (1990).

Magnusson et al. (1999). – teacher orientations

The Magnusson et al. conceptualization for PCK is the most widely cited framework for studying teachers' PCK (Gess-Newsome, 2015). Magnusson et al. stipulate that PCK is the "transformation of several types of knowledge for teaching (including subject matter knowledge), and that is such it represents a unique domain of teacher knowledge" (1999, p. 95). This transformation of Magnusson et al. is equivalent to Shulman's "blending of content and pedagogy" (1987, p.8). Magnusson et al. expand their definition, which in parts is identical to Shulman's (1987) definition:

> Pedagogical content knowledge is a teacher's understanding of how to help students understand specific subject matter. It includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners, and then presented for instruction. (p. 96)

In modified forms, Magnusson et al. fit Shulman's knowledge of learners and their characteristics, curriculum knowledge, and educational ends, purposes and values into their pedagogical content knowledge model (1999, p. 99). However, Shulman's PCK amalgam of two components, content knowledge and pedagogical knowledge (1987, p. 8), has been replaced with five science specific categories, some of which include multiple branches and prominently feature teacher orientations (Figure 4):

> (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and belief about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. (p. 97)

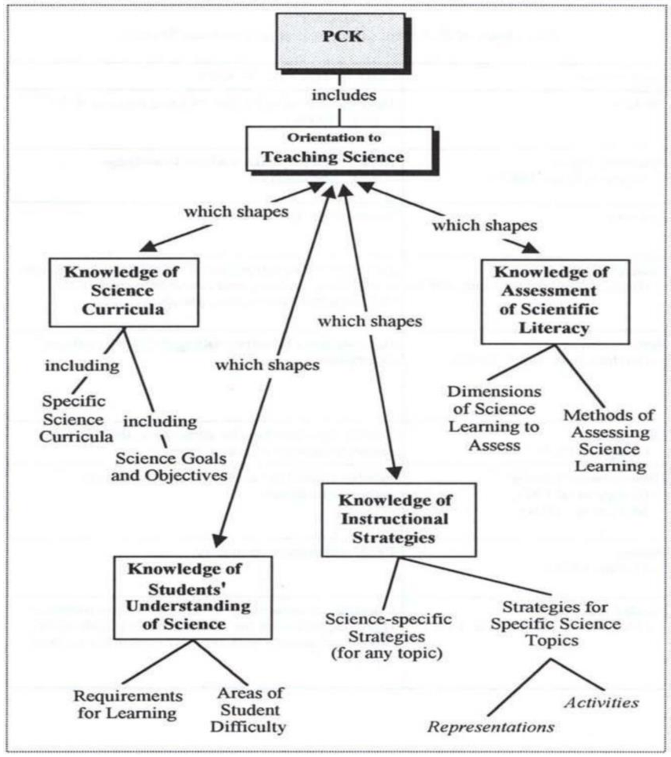

Figure 3. The Magnusson et al., 1999 model for the conceptualization of PCK. Note that there are five main components, and four interact and are directly influenced by the orientation to teaching science.

Magnusson et al. acknowledge "the importance of subject-specific knowledge in effective teaching," indicating that content knowledge contributes to the PCK used for teaching (1999, p. 96). Many aspects of Shulman's PCK are found in the Magnusson et al. PCK conceptualization and model, however, there are changes to the components of PCK, a reorganization of components with new boundaries, and new features have been added, most importantly orientations, that some researchers consider unclear and an oversimplification (Friedrichsen et al., 2011).

The visual appearance of the model with five new PCK components (Figure 3) is a radical departure from Shulman, who had conceptualized a model with two PCK subcomponents and Grossman, who included four; however, within these changes in structure, description, and organization, there exist many commonalities between Magnusson et al. and the seven knowledge domains of Shulman (1987).

The four domains of knowledge for Magnusson et al. are adapted from the above Grossman model (1990), adding beliefs to each domain: general pedagogical knowledge and beliefs, subject matter knowledge and beliefs, pedagogical content knowledge and beliefs, and knowledge of context and beliefs (Magnusson et al., 1999, p. 98). As noted, Shulman's (1987) PCK has no affective components. Magnusson et al. place the pedagogical content knowledge domain between the other three domains, and PCK is influenced by, and influences, the domains of subject matter knowledge, pedagogical knowledge, and knowledge of context.

Thus, the addition of beliefs and orientations by Magnusson et al. (1999) is a significant difference that embraces the emotional aspect of pedagogical choices within pedagogical content knowledge by stating that teachers will use "knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" (p. 97). Magnusson et al. (1999, p. 97) reference differences in teacher orientations, citing Borko and Putnam (1996) to describe the use of knowledge and beliefs as "a 'conceptual map' that guides instructional decisions about issues such as daily objectives, the content of student assignments, the use of textbooks and other curriculum materials and the evaluation of student learning. The PCK category of orientations (Magnusson et al., 1999) is further complicated by the nine suggested teacher orientations, including process, academic rigour, didactic, conceptual change, activity driven, discovery, project-based science, inquiry, and guided inquiry.

An example of the impact of orientations is found when one compares the didactic orientation's goal to "transmit the facts of science" as compared to the project-based science orientation that will "[i]nvolve students in investigating solutions to authentic problems" (p. 100). According to Magnusson et al., the nature of instruction associated with didactic teaching includes "lectures, discussions and questions directed to students to hold them accountable for knowing the facts produced in science." In contrast, project-based instruction is project-centred, involving activity where teacher and student activity "centers around a 'driving' question" involving investigation and development of artifacts to reflect understandings (p. 101). The central role of orientations in PCK for "decision-making relative to planning, and acting, and reflecting upon teaching" is admittedly hypothetical (Magnusson et al., 1999, p. 102) but including a teacher's orientation in PCK is radical relative to Shulman's conceptualization. However, the departure with Shulman (1987) is not absolute as within general pedagogical knowledge and content knowledge that grows during "pedagogical reason and action" (p. 15) there are aspects of decision making. Shulman (1987) stated that teachers demonstrating the process of decision-making in teaching to learn while teaching within the areas of adaptation, representation, and selection (p. 15). However, affective teacher beliefs for the general pedagogical knowledge that amalgamates with content knowledge to form PCK is not present in Shulman's conceptualization.

Magnusson et al. believe curriculum knowledge "represents knowledge that distinguishes the content specialist from the pedagogue knowledge – a hallmark of pedagogical content knowledge" (1999, p. 103). The knowledge of curriculum is positioned outside of PCK for Shulman (1987) but is located inside the PCK component "Knowledge of science curricula" of Magnusson et al. (1999, p. 103). Along with placing curriculum inside PCK, Magnusson et al.

also subdivide the category into "knowledge of goals and objectives" along with "knowledge of specific curricular program" (p. 103). The content of both categories includes the goals and objectives of the horizontal and vertical curriculum (described though not explicitly stated). The subcategory of "knowledge of specific curricular programs" connects to the reference to "knowledge of the programs and materials relevant to teaching a particular domain science and specific topics within that domain" (p. 103). The description of "knowledge of science curricula" by Magnusson et al. demonstrates strong similarities to the "curricular knowledge" elaborated by Shulman (1986) as the "for range programs designed for teaching of particular subjects and topics at a given level" that includes both lateral curriculum and vertical curriculum (p. 10). However, Magnusson et al. believe curriculum is the province of the pedagogue and, thus, place it within PCK versus isolating it as a knowledge domain.

Magnusson et al. PCK category "knowledge of students' understanding of science" refers to "the knowledge teachers must have about students to help them develop specific scientific knowledge" (1999. p, 104). This PCK category includes two subcategories. The first subcategory, "knowledge of requirements for learning," includes:

> … teachers' knowledge and beliefs about prerequisite knowledge for learning scientific knowledge, as well as their understanding of variations within students' approaches to learning as they relate to the development of knowledge within specific topic areas. Teacher knowledge of prerequisite knowledge required for students to learn specific concepts includes knowledge of abilities and skills that students might need. (p.104)

The second subcategory, "knowledge of areas of student difficulty," refers to "teachers' knowledge of the science concepts or topics that students find difficult alert there are several reasons why students find learning difficult in science, and teachers should be knowledgeable about each type of difficulty" (p.105).

According to Shulman (1986), PCK "includes an understanding of what makes the learning of specific topics easy or difficult" and strategies to address these preconceptions or misconceptions (p. 9). Shulman (1987) added a domain, "knowledge of learners and their characteristics" (1987, p. 8), with a little explanation. However, in the "Model of Pedagogical Reasoning and Action," there are details of adaptation and tailoring to student characteristics to address "preconceptions, misconceptions, and difficulties, language, culture and motivations…" (p. 15). The Magnusson et al. model contains more elaborations, such as detailed explanations of the role of misconceptions on learning (1999, p. 105), and demonstrates the complexity of the knowledge of students' understanding of science.

Magnusson, et al.'s knowledge of assessment and science component, has no comparable category in Shulman's domains of teacher knowledge save a short section from the Grossman case study (Shulman, 1987, pp. 18–19) that provides little detail about this vital component teacher knowledge. Magnusson et al. present two sub-categories for the PCK component, "knowledge of assessment in science" (1999, p. 108). Teachers' "knowledge for dimensions of science learning to assess" includes "aspects of students learning that are important to assess within a particular unit of study" (1999, p. 108). The second sub-component, the "knowledge of methods of assessment," includes teachers' knowledge for "assessing the specific aspects of student learning that are important to a particular unit of study" (p. 109). Both subcategories of Magnusson et al. are supported with significant references to the literature and provide examples to clarify the content and significance of each subcategory. Shulman does not describe evaluation within his teacher knowledge bases or in the model of PCK.

The most extensive and last section of Magnusson et al. is the "Knowledge of instructional strategies" (1999, p. 109) and starts with the author's review of the research of evidence to support their claim that "teachers' use of strategies is influenced by their beliefs" (p. 111). This section has two subcategories, one is "knowledge of subject specific strategies," which represents general approaches for science instruction (such as the learning cycle or inquiry), and the other is "knowledge of topic specific strategies," which describes topic specific with representations (such as illustrations and analogies) (p. 111) and topic specific activities (p. 113). This section differentiates between subject specific and topic specific PCK for instruction and illustrates this important subject/topic PCK knowledge theme also found in the knowledge of science curriculum (p. 103). Shulman does specify subject/topic levels of organization for PCK.

Park and Oliver's (2008) conceptualization of PCK and teacher knowledge

The PCK literature expanded significantly since Magnusson et al. (Abell, 2007; Grossman, 1990; Gess-Newsome, 1999) and the Park and Oliver (2008) literature review considered a corpus of research to conceptualize their definition of PCK as a:

> … teacher's understanding and enactment of how to help a group of students understand a specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment. (p. 264).

The Park and Oliver definition for their model (Figure 4) is more specific than Shulman's PCK (1987). It goes beyond "professional understanding," and the importance of enactment explicitly stresses the importance of assessments in teaching and learning and identifies the significance of context of the teaching or learning environment. However, it is noteworthy that Park and Oliver acknowledge that "it is transformation of subject matter knowledge for the purpose of teaching that is at the heart of the definition of PCK" (2008, p. 264), and thus, they support Shulman's central claim that PCK is a "blending content and pedagogy" that forms the professional knowledge used to help learners (1987, p. 8).

The four domains of teacher knowledge used by Park and Oliver (2008) are similar to Grossman's (1990), where the pedagogical content knowledge domain is located between and is influenced by and controls the domains of subject matter knowledge, pedagogical knowledge, and knowledge of context. The Park and Oliver (2008) PCK components include orientation to teaching, knowledge of assessment of science learning, knowledge of instructional strategies for teaching science, knowledge of students' understanding of science, knowledge of curriculum, and teacher efficacy; note that orientation is specific to teaching, a change from Magnusson et al. (1999). The Park and Oliver model (Figure 4) displays six components that form a hexagon and integrate through the center using reflection-in-action and reflection-on-action. Park and Oliver believe "PCK encompasses both teachers' understanding and their enactment" (p. 263). They support this understanding and enactment belief, citing Baxter and Lederman's (1999) statement that "PCK is both an external and internal construct, as it is constituted by what a teacher knows, what the teacher does, and the reasons for the teacher's action" (p. 158). Reflection is not a component of Shulman's PCK (1987), although he described the act of teaching, reflection, and transformation as vital for developing PCK.

The original PCK model discussed in the Park and Oliver (2008) literature review contains five components, each drawn from the work of Grossman (1990), Tamir (1988), and Magnusson et al. (1999). "Teacher efficacy: An Affective Affiliate of PCK" was added as a sixth component as "an ancillary aspect of PCK" (p. 270). Efficacy in the classroom context is how the belief in one's capability to execute their PCK effectively leads to more PCK enactment in actual classrooms (p. 270). Shulman's conceptualization of PCK and teacher knowledge forms do not contain an affective component to account for teacher beliefs.

An interesting aspect of the Park and Oliver PCK model is the orientations subcategory of "beliefs about the nature of science" (p. 279; Figure 4). Park and Oliver (2008) follow Magnusson et al. in stating that orientations influence "the transformation of teacher knowledge from other knowledge domains into PCK" (p.266) and guide instructional decisions such as choice of instructional strategies or forms of assessment stay. Abd-El-Khalick (2013) described how understanding the nature of science helps "develop informed epistemological understandings about the generation and validation of scientific knowledge, and the nature of the resultant knowledge" (p. 2090). Thus, the addition of the nature of science would include syntactical knowledge, a component of Shulman's (1987) content knowledge domain.

Park and Oliver add another difference when compared to Shulman with the subcategory of curriculum saliency. Similar to Magnusson et al. (1999), the curriculum is inside PCK for Park and Oliver (2008) as opposed to being outside the PCK for Shulman (1987). This understanding enables "teachers to identify core concepts, modify activities, and eliminate aspects judged to be peripheral to targeted conceptual understanding" (p. 266).

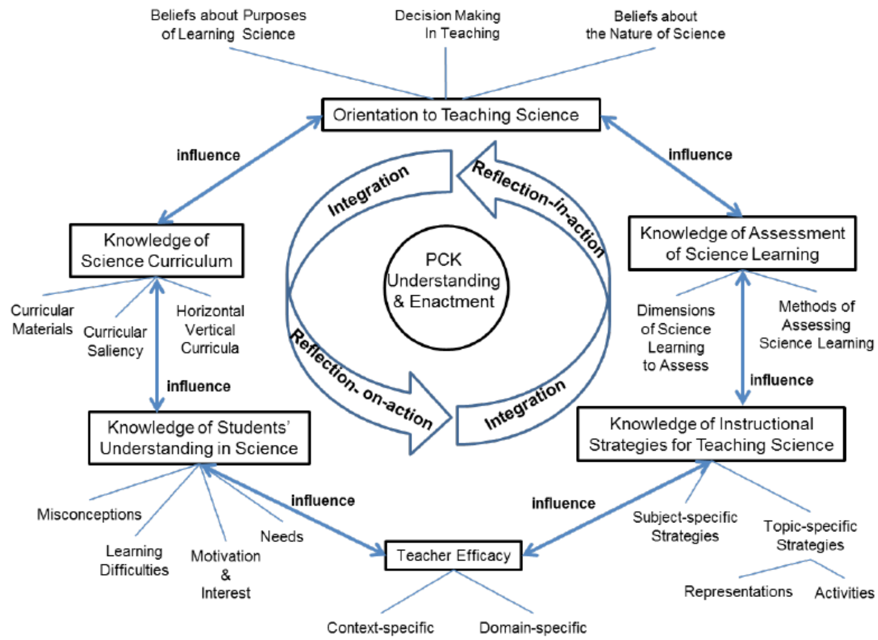

Figure 4. The Park and Oliver (2008) PCK model. Relative to Magnusson et al. model Park and Oliver, the number of PCK components increased from 5 to 6, and the number of PCK subcomponents rose from 10 to 20.

Gess-Newsome (2015) Model of Teacher Professional Knowledge and Skill that Includes PCK

The PCK Summit of 2012 was momentous for the discourse and brought together 22 science educators from seven countries to construct a consensus model of PCK (Carlson et al., 2015). The abridged version of the summit's two ambitious goals were to "explore the potential for a consensus model of PCK… [and identify] specific next steps that would move the field forward" (p. 15), harkening back to the call by Lawrenz (1975) to find connections between teacher characteristics and student outcomes. The summit participants made significant progress in redefining and locating PCK in specific contexts.

Comparison of Gess-Newsome's (2015) definition of PCK and Shulman's conception of PCK.

The context, "Classroom practice is the location of PCK" (p. 36), gave PCK a specific location not included in the Shulman PCK conceptualization (Figure 5). The Summit members also proposed two forms of PCK, personal PCK (pPCK) and PCK&S (the "S" represents skill) and placed PCK at the topic level (changing the grain size from subject or discipline). The proposed definition of pPCK is "the *knowledge* of, *reasoning* behind, and *planning* for teaching a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes* (Reflection *on* Action, Explicit)" (p. 36). Personal PCK&S is defined as "the act of *teaching* a particular *topic* and a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes* (Reflection *in* Action, Tacit or Explicit) (p. 36). The personal, skill and topic-level designations that include student outcomes differ from Shulman's PCK (1986, 1987). The Summit definitions effectively separate Shulman's transformative act of understanding and blending of topics "to diverse interests and abilities of learners" in lesson preparation as pPCK from "presented for instruction" (p. 8), the declarative and procedural action of actively teaching that is PCK&S; Shulman did not elaborate procedural skill.

Gess-Newsome (2015) Model of PCK and Teacher Knowledge.

Figure 5 depicts three types of teacher knowledge. The most generic teacher knowledge is termed "Teacher professional knowledge bases." It includes assessment knowledge, along with Shulman's (1987) pedagogical knowledge, content knowledge, knowledge of students, a modification of Shulman's, knowledge of learners in their characteristics (1987, p. 8), and curricular knowledge (Gess-Newsome, 2015, p. 31). These knowledge bases (or Shulman's domains) are influenced by and influence "Topic-specific professional knowledge" that includes instructional strategies, content representations, and student understandings (p. 31). This knowledge is held by the profession and public, similar to Shulman's content knowledge but at a topic level.

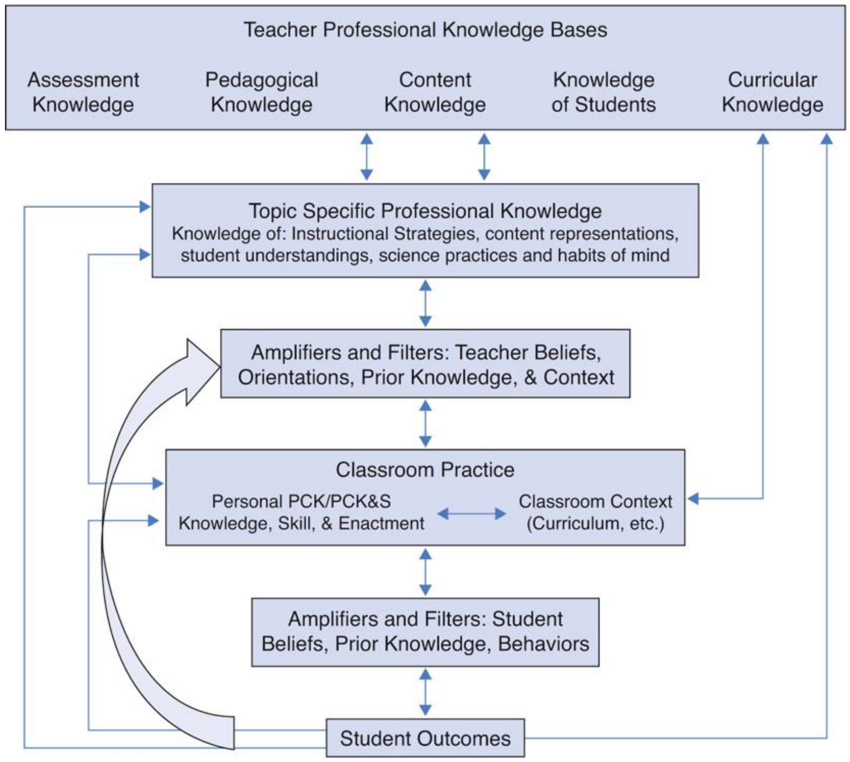

Figure 5. The model of teacher professional knowledge and skill that includes PCK (Gess-Newsome, 2015).

The topic-specific grain size and location of pPCK and PCK&S in the classroom acknowledge the impact that context has on both forms on pPCK and PCK&S. Unlike Shulman's PCK (1986, 1987) filters and amplifiers (affective factors such as orientations and beliefs) influence pPCK and PCK&S. Filters block pPCK and PCK&S components (not teaching evolution) while amplifiers enhance chosen aspects of pPCK and PCK&S (e.g., the personal importance of Darwinian horse evolution). The view of PCK is relatively limited within the Consensus Model and is addressed with the Refined Consensus Model.

The Refined Consensus Model of PCK

The Refined Consensus Model of teachers' PCK (Carlson et al., 2019) was developed in response to several shortcomings of the 2012 PCK Summit (Gess-Newsome, 2015) and to clarify how it is different from the PCK of the Shulman (1987) and Magnusson et al. (1999) models.

Carlson et al. (2019) definition of PCK vs. Shulman's conception.

Carlson et al. (2019) did not conceptualize one alternative to Shulman's (1987) PCK; they conceptualized three forms: enacted PCK (ePCK), personal PCK (pPCK), and collective PCK (cPCK). Carlson et al. (2019) stated the ePCK is knowledge used in the practice of teaching "is the specific knowledge and skills utilized by an individual teacher in a particular setting, with a particular student or group of students, with the goal for those students to learn a particular concept, collection of concepts, or a particular aspect of the discipline." (p. 85)

Carlson et al. (2019) noted that enactment or practice includes "knowledge and reasoning behind the act" as teachers plan, teach, and reflect with ePCK (p. 85). The acts of planning and teaching connect directly with the Shulman (1987) PCK as knowledge of "how particular topics, problems, or issues are organized, represented, and adapted to the diverse interest and abilities of learners, and presented for instruction" (p. 8). Shulman's (1987) Model of Pedagogical Reasoning in Action is also found in ePCK when Carlson et al. (2019) emphasize "the acts of planning and instruction and reflecting on instruction" (p. 85). However, Carlson et al. (2019) ePCK suggested that "pedagogical reasoning that takes place during all aspects of teaching is unique to each teacher and every teaching moment" demonstrates the dynamic individuality and fleeting nature of ePCK not found in Shulman's conceptualization. Further, Carlson et al. (2019, p. 85) "reflection on student outcomes" does not parallel Shulman's PCK.

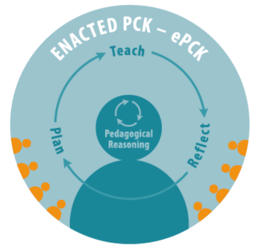

Figure 6a. Enacted PCK represents the teacher's knowledge and skills "used in a particular setting to achieve particular student outcomes" (Carlson et al., 2019, p. 84). The teacher is the single large caricature, and the students are the eight small caricatures.

Figure 6b. Personal PCK is the cumulative reservoir of learned PCK that can be used as ePCK (as teaching or planning). The arrows represent the knowledge exchange between ePCK and pPCK that may be filtered or amplified through pedagogical reasoning. The caricatures represent everyone, including students, who contributed to the teacher's pPCK growth (Carlson et al., 2019, p. 84).

The model of ePCK (Figure 6a) demonstrates the cycle of pedagogical reasoning in the teacher caricature. Pedagogical reasoning's decisions make ePCK visible as a "teacher's expression of knowledge, choice of strategies and representations" (p. 86). In the Refined Consensus Model, "knowledge of and reasoning behind the act of teaching when interacting directly with students" is reflection in action. In contrast, "the acts of planning instruction and reflecting on instruction in student outcomes" is reflection on action (p. 85). Shulman (1987) does not account for reflection in action but considers reflection on actions (p. 15). Visible components of ePCK include some of Shulman's domains, such as knowledge of students, curriculum, and assessment knowledge, while beliefs are not present in Shulman's (1987) PCK.

Personal PCK (pPCK) is "the cumulative and dynamic pedagogical content and skills of an individual teacher" collected during teaching, contact with others (teachers and other professionals), and any personal learning experience, including all the students the teacher has ever taught (Carlson et al., 2019, p. 87). The PCK and knowledge domains of Shulman (1987) would represent significant aspects of pPCK except for student outcomes, teacher orientations, and beliefs. The arrows of the model (Figure 6b) describe the knowledge exchange between ePCK and pPCK that may be filtered or amplified through pedagogical reasoning (p. 87).

The pPCK context and teacher knowledge bases.

The context of pPCK includes any factor that connects to the learning environment, such as curriculum and individual student attributes. Knowledge of learning contexts will be "deep" and include contexts that are both distal and more proximal to their students. Learning contextual factors connect to and through pPCK to ePCK and may "serve to both amplify or filter each teacher's knowledge and skills to mediate teacher's actions" (Carlson et al., 2019, p. 88). This layer of the model (Figure 7) separates pPCK from cPCK.

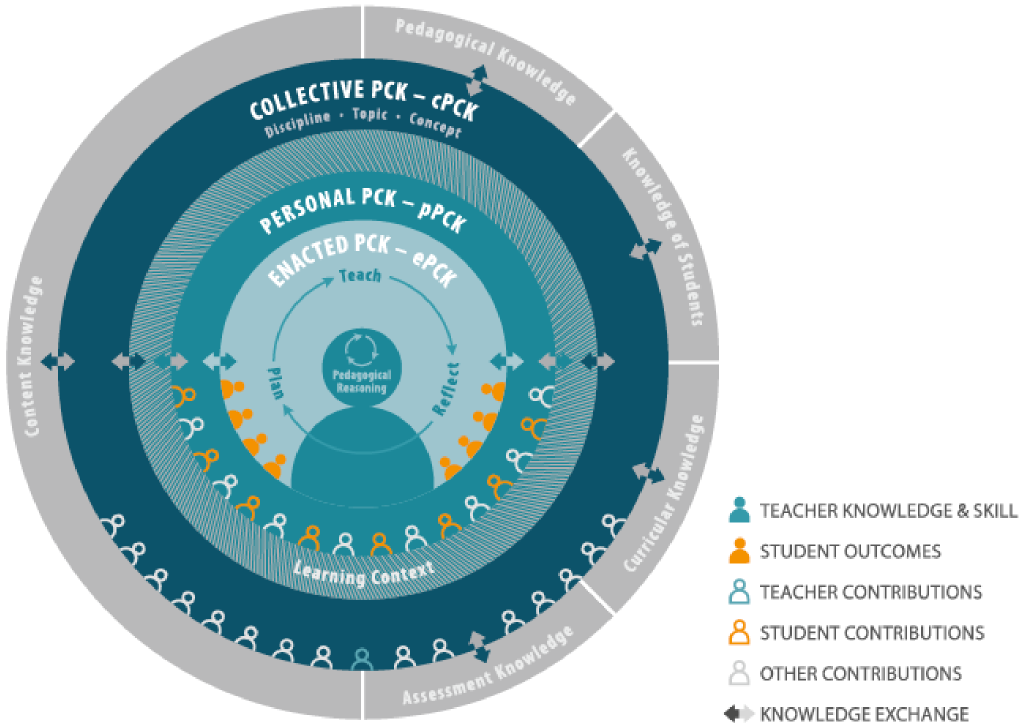

Figure 7. The Refined Consensus Model of teachers' pedagogical content knowledge and teacher knowledge bases.

A researcher or practitioners can document collective PCK, which varies from "discipline-specific to topic specific to content specific PCK" (Figure 7). Collective PCK is "an amalgam for multiple science educator's contributions including the teachers own contributions" and includes knowledge bases that can be shared and considered public (p. 90). The cPCK is surrounded by knowledge bases that are foundational for all three forms of PCK and include: pedagogical knowledge, knowledge of students, curricular knowledge, assessment knowledge, and content knowledge (p. 91). These knowledge bases were identified by Shulman (1987) and, over time, have experienced elaborations.

Evolution of PCK Discourse

Based on the above review it is evident that the PCK discourse has, through much effort, evolved since Shulman's initial conception (Table 1). The knowledge bases changed. However, content knowledge and pedagogical knowledge remain the major contributors to PCK (Gess-Newsome et al., 2019). Grossman (1990) introduced the first model and reorganized PCK to have four components, informed by three other domains (subject matter knowledge, pedagogical knowledge and context knowledge). Beliefs from affective domain were included in PCK by Grossman (1990).

Table 1.

Conceptualizations of PCK, 1987 to present.

Author(s)	Knowledge Domains or Bases	Types of PCK	PCK components & Subcomponents	Beliefs or Affective Components	Considers Student Outcomes	Reflection on action/ in action	Amplifiers & Filters
Shulman (1987)	7	PCK	2 components	No	No	Yes / No	Filters
Grossman (1990)	4	PCK	4 components	Yes	No	Yes / No	Filters
Magnusson et al. (1999)	4	PCK	5 components 10 subcomponents	Yes	Yes	Yes / No	Filters
Park & Oliver (2008)	4	PCK	6 components 20 subcomponents	Yes	Yes	Yes / Yes	Filters Efficacy*
Gess-Newsome (2015)	5 or more	pPCK PCK&S	Not specified	Yes	Yes	Yes / Yes	Both
Carlson et al. (2019)	5 or more	ePCK pPCK cPCK	Not specified	Yes	Yes	Yes / Yes	Both

*Efficacy can serve to filter of amplify and varies by teacher.

Next, Magnusson et al. (1999) radically diversified the composition of PCK, adding orientations to teaching and four new components with ten subcomponents. Beliefs were located in each domain (PCK, subject matter knowledge, pedagogical knowledge and context knowledge) while PCK became more science focused. Shulman was present to some degree, minus the affective domain, in the knowledge of science curriculum, the knowledge of students understanding of science, knowledge of assessment to a lesser degree, and knowledge of instructional strategies. Like Shulman, Magnusson et al. state that PCK is a transformative knowledge form. Magnusson et al. (1999) significantly influenced Park and Oliver's (2008) PCK elements, except teacher efficacy. Park and Oliver added reflection in and on action to their hexagonal model and new definition elements on assessment and contextual factors (cultural and social limitations in the learning environment).

Two forms of PCK were conceptualized by the first PCK Summit and reported by Gess-Newsome (2015). PCK was located in the class context, was personal as pPCK and included skill for the first time. Three levels of knowledge were forwarded, student outcomes were promoted, and a knowledge base (assessment knowledge) was added. Carlson et al. (2019) refined the locations of PCK at the level of enactment in, with, or for students (ePCK), personal knowledge for teaching (pPCK), and collective knowledge of all (cPCK). The new definitions acknowledge context, student outcomes, filters and amplifiers, and the manner of their impact on the three forms of PCK. Yet, among those differences with Shulman’s (1987) conception is the backbone he conceived; the knowledge domains, pedagogical reasoning, reflecting *on* teaching, and the transformation of knowledge into the PCK “amalgam” to form is a professional understanding that is “uniquely the province of teachers” (p. 8).

Student Inquiry for Learning Science – definitions, curriculum, benefits, and challenges

What constitutes inquiry-based science teaching? In Canada and the United States, science curricula have changed significantly in the past 30 years in an attempt to include more active learning in K-12 science courses: Canada – CMEC (1997) Common framework of science learning outcomes, K to 12; USA – National Research Council (2012), A Framework for K12 Science Education. These reforms are not restricted to North America (Coll & Taylor, 2012) with examples of significant shifts in Europe (Leaton et al., 2018), Asia (Kim et al., 2015; Lee, 1992), Africa (Chisholm & Leyendecker, 2008), and Australia (Lowe & Appleton, 2015).

Bybee (2006) stated that student inquiry in science is a form of learning where students answer questions about the natural world through scientific investigations, similar to scientists. In doing so, they become the center of their learning while their teachers acted as facilitators. Student inquiry is similar to scientists' work as it involves observation and some scientific practices. According to Minner et al. (2010), the term inquiry refers to three distinct categories of learning activities: what scientists do, how students learn, and the pedagogical approach by teachers (p. 476). Everett and Moyer (2007) reported a key component of inquiry science instruction is using activities where students investigate questions to which they do not know the answer. Banchi and Bell (2008) suggested that a scientific inquiry may take several forms: confirmation, structured, guided, and open inquiry. For example, a lab that reinforces a well-known phenomenon using a demonstration is considered a confirmation inquiry. However, in an open inquiry, the students develop the questions and experimental design and then provide a solution (Banchi & Bell, 2008, p. 27).

The level of a student science inquiry

In the autoethnography of inquiry-based teaching of genetics (Wells, 2017), I employed Chinn and Malhotra's (2002) conceptualization of authentic scientific inquiry to examine my use of inquiry for teaching genetics. The levels of inquiry for students differ from those used by scientists to generate new knowledge. The Chinn and Malhotra definitions of the level of inquiry are as follows:

1. Authentic Inquiry – scientific research in the form of case studies or experiments (p. 178).
2. Simple Experiments – a straight forward experiment which usually examines the relationship between one independent and one dependent variable (p. 179).
3. Simple Observations – where students make, observe, and describe objects (p. 179).
4. Simple Illustrations – When students follow a procedure, without a control condition, and observe the outcome (p. 179).

These types of inquiry differ in terms of the level and type of their reasoning, the degree of guidance from the teacher, and the dimension of epistemology experienced by the students. Significant scientific rigor, such as the theory-ladenness of methods, is expected to achieve Chinn and Malhotra's authentic science inquiry classification. I found that Chinn and Malhotra's authentic inquiry is only possible when a student conducts a Science Fair project under the supervision of a scientist (Wells, 2017). Therefore, the Chinn and Malhotra definition is too narrow to consider the day-to-day inquiries in a typical science class, where authentic inquiry is rare. A classification system grounded in teaching activities would be better suited for conducting lesson studies to learn about inquiry-based instruction.

Blanchard et al. (2010, p. 581) adapted the levels of inquiry from several authors to develop a table that more suitably considers inquiry by the source of the question, data collection methods, and interpretation of results. The Blanchard et al. (2010) conceptualization is for middle school and high school, where students interpret results versus “finding solutions” for elementary students (Banchi & Bell, 2008, p. 27).

Table 2.

Levels of Inquiry from Blanchard et al. (2010)

Level of Inquiry	Source of the Question	Data Collection Methods	Interpretation of Results
Level 0: Verification	Given by teacher	Given by teacher	Given by teacher
Level 1: Structured	Given by teacher	Given by teacher	Open to student
Level 2: Guided	Given by teacher	Open to student	Open to student
Level 3: Open	Open to student	Open to student	Open to student

The categories of Minner et al. (2010), what scientists do, how students learn, and the pedagogical approach teachers use complement the Blanchard et al. (2010) interpretation of student inquiry levels. The Blanchard et al. classification system focuses on the seminal aspects of student inquiry - who is the source of questions, the data collection methods, and the interpretations of results.

Curriculum and Inquiry Instruction

The National Research Council's (2012) Practices for K-12 Classrooms recognize “that students cannot reach the level of competence of professional scientists and engineers any more than a novice violinist is expected to attain the abilities of her virtuoso” (p. 49). The eight practices considered essential for the K-12 science and engineering curriculum are:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in an argument from evidence
8. Obtaining, evaluating, and communicating information (p. 49)

These practices are components of inquiry that help students make sense of the world (Schwarz et al., 2017). Collectively the Practices for K-12 Classrooms resemble the broad areas of the Integrated Skills Unit found in the NLDE (2018) Science 1206 Curriculum Guide:

- Initiating and Planning - These are the skills of questioning, identifying problems, and developing initial ideas and plans.
- Performing and Recording - These are the skills of carrying out action plans, which involves gathering evidence by observation and, in most cases, manipulating materials and equipment.
- Analyzing and Interpreting - These are the skills of examining information and evidence of processing and presenting data so that it can be interpreted, and interpreting, evaluating, and applying the results.
- Communication and Teamwork - In science, communication skills are essential at every stage where ideas are being developed, tested, interpreted, debated, and agreed upon. Teamwork skills are also important, since the development and application of science ideas is a collaborative process both in society and in the classroom. (p. 28)

Students should be allowed to develop and apply their skills in various contexts. These contexts connect to the STSE component of the curriculum by linking to three processes for skills application:

1. Science inquiry - seeking answers to questions through experimentation and research
2. Problem-solving - seeking solutions to science-related problems by developing and testing prototypes, products, and techniques to meet a given need.
3. Decision-making - providing information to assist the decision-making process. (p. 28)

Science curriculum developers specify that students conduct scientific practices, such as inquiry, because of their positive impact on students.

The Benefits of Student Inquiry Learning

Using inquiry-based instruction has been linked to improved student achievement, increased intrinsic motivation, and improved performance on high-stakes tests (Blanchard et al., 2010; Saunders-Stewart et al., 2012). Inquiry promotes the active construction of knowledge by investigating questions versus memorizing knowledge (Duran & Duran, 2004). Further, inquiry can "help students construct fundamental science concepts" (Chiappett, 1997, p. 26), and evidence suggests that using inquiry increases student critical thinking skills (Kitot et al., 2010). Kawalkar and Vijapurkar (2015) examined student writing and found that inquiry leads to conceptual clarity where students who conducted an inquiry in science "came up with explanations, then communicated conclusions with convincing arguments" (p. 2143). DiBiase and MacDonald (2015) suggested that inquiry-based instruction engages students more than teacher centered instruction. The inquiry also provides opportunities for multimodal forms of learning, making learning more personal for students with different educational needs (Duran & Duran, 2004, p. 55). Despite the positive attributes of inquiry-based instruction outlined above, a group of researchers recently posited that inquiry-based instruction is deleterious for students.

In 2006, Kirshner et al. wrote a commentary based on cognitive load theory, which suggests that minimal guidance during the learning activities, such as the four forms of inquiry in Table 2, hinders memory formation. Kirshner et al. (2006) are correct that humans have a finite ability to hold information in their working memory (based on the widely accepted model of Atkinson & Shiffrin, 1968). However, their arguments regarding inquiry-based instruction broadly attack constructivism based on open inquiry - the highest level of inquiry (Hmelo-Silver et al., 2007). Kirshner et al. (2006) focused their critique on inquiry using discovery learning as their example of inquiry. Discovery learning includes activities that would be Level 3 or open, according to Blanchard et al. (2010). By definition, an open inquiry does not offer students instructional support (see Table 2), yet, most forms of inquiry require that teachers buttress their students' learning (Hmelo-Silver et al., 2007). This counterargument to Kirshner et al. (2006) by Hmelo-Silver et al. (2007) rightly criticizes the grouping of many different forms of teaching, such as inquiry, problem-solving, and lab investigations under the category of unguided (level 3).

> Kirschner and colleagues have indiscriminately lumped together several distinct pedagogical approaches—constructivist, discovery, problem-based, experiential, and inquiry-based—under the category of minimally guided instruction. We argue here that at least some of these approaches, in particular, problem-based learning (PBL) and inquiry learning (IL), are not minimally guided instructional approaches but rather provide extensive scaffolding and guidance to facilitate student learning. (p. 99).

Further evidence used to counter the claims of Kirschner et al. is the inquiry studies that "show significant and marked effect sizes and gains in favour of inquiry-, problem-, and project-based environments" (Hmelo-Silver et al., 2007, p. 103). Since 2007, more studies have documented inquiry-based instruction's learning benefits (Blanchard et al., 2010, Furtak et al., 2012; Lin et al., 2014; Marshall & Alston, 2014; Minner et al., 2010). However, problems arise for teachers and students during inquiry science instruction. The controversy fabricated by Kirshner et al. (2006) remains unresolved for some educators. Nevertheless, those who practice inquiry believe it is worth the effort (Zhang, 2016).

Challenges of Instructing Using a Student Inquiry Approach

Teaching via inquiry challenges both novice and experienced teachers (Capps et al., 2016; Chichekian et al., 2016). Several forms of inquiry create discomfort for teachers by requiring them to relinquish some classroom control to produce independent learners (DiBiase & McDonald, 2015; Dunkhase, 2003; Goodnough, 2016; Goodnough et al., 2014). When students conduct an inquiry, they are the center of their learning (Blanchard et al., 2010), and this positioning differs from didactic instruction and is unfamiliar to some teachers. An inquiry class is reportedly more “complicated and messy” to manage (Neumann, 2013, p. 172) and has a more diverse workload than a teacher-centred class (Harris & Rooks, 2010). In their survey of 275 science teachers from North Carolina, DiBiase and McDonald reported that teachers “do not feel prepared to implement inquiry, nor do they have the skill necessary to manage inquiry activities” (2015, p. 33). Teachers have expressed concerns about student inquiry, citing the increased time for implementing inquiry in the classroom (Dunkhase, 2003). Further, the technical support of inquiry learning is time-consuming and requires the skill to use and manage materials (Harris & Rooks, 2010). A classroom teacher must be well-versed in supporting and managing the devices when students collect data using tools similar to those used by research scientists (Wells et al., 2017).

Students also need help with inquiry-based instruction. Many students are unfamiliar with inquiry may need help transitioning from traditional didactic instruction (Wells & Ricketts, 2023). Similarly, Donnelly et al (2014) reported that when inquiry is not a component of the classroom culture, tension may form between the teachers and students during the inquiry process. Evidence suggests that experienced teachers support student inquiry and demonstrate a "tolerance for student confusion" versus helping students find the quickest solution for a problem (Donnelly et al., 2014, p. 2047). Moreover, controlling student behaviour inhibits learning and "classroom management in inquiry classrooms should be aimed at creating conditions that support students' reasoning around conceptual issues and complex problem solving" (Harris & Rooks, 2010, p. 230).

Research shows that a teacher's methods of pedagogy are strongly linked to the style of teaching they receive as a student (Wong & Luft, 2015). Also, some experienced teachers are "resistant to adapting to novel instructional practices" (McDonnough & Henschel, 2015, p. 148). Haney et al. (2003) found that when beliefs within an educational community lack congruency, reforms that include student inquiry are not likely to persist (2003). In the face of these obstacles, it would seem that educators who wish to teach using inquiry-based instruction will require significant support.

Professional Learning and Inquiry-Based Science Instruction

Professional learning and the development of professional learning communities are reportedly crucial to increasing the number and quality of high school science inquiry lessons (Blanchard et al., 2013; Marshall, 2008; Miranda & Damico, 2013, 2015). Marshall et al. (2011) reported that short-term professional development fails to produce inquiry-proficient teachers, while long-term PD and conducting teacher research are excellent support for successful implementing inquiry-based instruction (Goodnough, 2010; Miranda & Damico, 2013, 2015; van Zee, 2006). Research suggests that challenging teacher beliefs should be addressed with post-secondary education (Vaino et al., 2013), appropriate PD (DiBiase & McDonald, 2015), and proper teacher induction (Wong & Luft, 2015).

Developing an understanding of teacher learning by combining the guiding structure of a PCK framework and including student outcomes is called for in recent PCK literature (Carlson et al., 2019). In a local high school setting, Wells et al. (2017) successfully facilitated teacher PD within a professional learning community to develop inquiry-based techniques. Teacher commitment to learning was substantial and resulted in teacher learning for inquiry; however, this study's analysis was limited and lacked a guiding theoretical perspective (Wells et al., 2017). A recent local practitioner action research project reported high school teacher and student learning while conducting inquiry-based instruction (Wells & Ricketts, 2023). In their study, Wells and Ricketts (2023) used the Park and Oliver (2008) model to report changes in teacher PCK. They connected some of these changes with misconceptions found within student evaluations. The three manuscripts that follow examine student and teacher outcomes to understand better high school teachers' reflection in and on action (Park & Oliver, 2008) while teachers plan, teach, and reflect (Carlson et al., 2019).

Cultural-Historical Activity Theory (CHAT)

In this section, I introduce Cultural Historical Activity Theory (Engeström, 1987) or CHAT. CHAT is the theoretical perspective used in the final manuscript chapter which contains an extensive literature review. The subsequent review will place situate this sociocultural theory in the contexts of online LS for remote science inquiry instruction and define the basic tenets of

CHAT.

Why study sociocultural factors?

Psychology demonstrates the significance of sociocultural influence over the individuals within a culture, particularly during our development (Rogoff, 2003). In adults, Solomon Asch (1948) established that social pressure influences decision-making, Phillip Zimbardo (2007) revealed the power of social roles in shaping human behaviour based on his work conducting the 1971 Stanford Prison Study, and Stanley Milgram in 1965, illuminated the dynamics of power relationships with authority figures. These seminal investigations starkly demonstrate the overt impacts of social power and influence over individuals within a culture. History is rife with records of the struggle for change in the face of sociocultural forces. The transformation of the Feudal System (Wessels, 2014) and the rise of Modernity (Anstey & Schuster, 2005; Wessels, 2014) occurred over several hundred years. A reasonable question is: Why do social changes that seem to be common sense take so long? The answer to this question is complex and depends on the culture and the degree of change required (Wessels, 2014; Schein, 2010).

In analyzing my transformation towards teaching science via student inquiry, I describe the influence of my past occupations and learning experiences as a teacher (Wells, 2017). In addition, I explain how social forces such as approval from teachers and administrators acted like rewards within my world. When I worked towards changing my pedagogical stance, I felt discomfort, and upon reflection, the shift in teaching style required more effort and time than expected (Wells, 2017).

How is teaching situated as a culture?

My personal teaching experiences and reflection on the literature on social change and organizational culture support the notion that the sociocultural variables found by Asch (1948), Zimbardo (2007), and Milgram (1965) exist within the world of teachers (Schein, 2010). There are parallels between the schools and teachers of education and Schein's "subcultures" and "microcultures" of organizational culture (2010, p. 2). Schein (2010) characterizes occupations, such as teaching, as cultures using the following description:

> If there is strong socialization during the education and training period and if the beliefs and values learned during this time remain stable as taken-for-granted assumptions even though the person may not be in a group of occupational peers, then clearly those occupations have cultures. (p. 20)

Schein suggests that cultures, such as science teacher microcultures, have three levels: artifacts, espoused beliefs and values, and basic underlying assumptions. These "visible and feelable structures and processes" and "unconscious taken-for-granted beliefs and values" (p. 24) include rules and behaviours such as how to teach specific topics, style of pedagogy, evaluation, and professional learning. Stone and Hart (2019) found that when working with others in a complex social context "process is rife with ambiguities and uncertainties" (p. 23). Professional learning is a source of change and is often resisted by teachers, especially during pedagogical changes (McDonnough & Henschel, 2015; Wong & Luft, 2015). Overcoming taken-for-granted beliefs and values requires a form of ongoing professional development such as action research (Goodnough, 2016; 2010) or LS (Lewis et al., 2006). Vygotsky (1978) might suggest Schein's artifacts, espoused beliefs, and values within ongoing professional development are forms of cultural mediation. How Vygotsky and other authors combined culture to human activity adds clarity to the concept of mediation.

Activity and mediation – essential elements of CHAT

Engeström's theory of human cultural-historical activity was influenced by prominent members of the Vygotsky School of Psychology (Vygotsky, Luria, and Leont've) when he developed the first and second-generation models of CHAT (Wertsch, 1981). The first-generation activity system of Engeström (1987, Figure 8) includes Vygotsky's (1978) depiction of mediation (X) influence on the response (R) to a stimulus (S). Engeström adapted this for CHAT to demonstrate how a Subject conducts actions and operations within activity towards the Object. For example, for a teacher (subject) instructing students, the instruction itself is an action, a goal-directed activity (Leont've, 1982). Within an activity examination of teaching, the presentation of the lesson is, however, an operation that would vary by the classroom and student conditions (Leont've, 1982). For example, if a student required a demonstration of an apparatus, the demonstration is an operation. Wertsch (1981) summarized the levels of analysis and the criteria used to define each level according to Leont've:

> Activities are distinguished on the basis of their motive and the object toward which they are orientated; actions, on the basis of their goals; an operation, on the basis of the conditions under which they are carried out. (p. 18)

Consider the teaching of cell biology: teaching is an activity mediated by artifacts, including a curriculum for cell biology for the teacher and images of the cell for the student. These mediating artifacts impact teaching and learning by the student with socially shared cognitive and physical resources (Vygotsky, 1978).

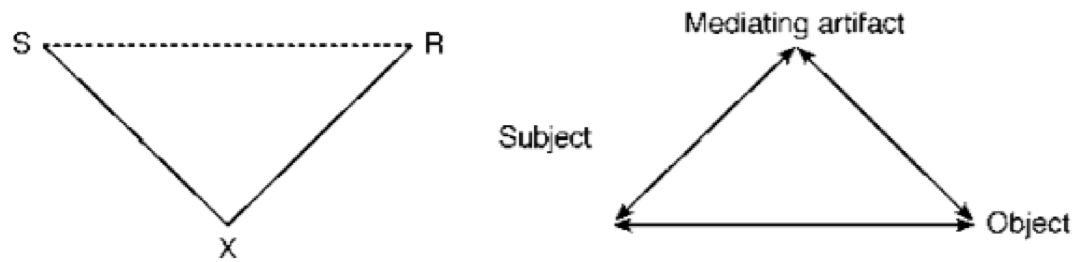

Figure 8. A First-Generation Activity System (Engeström, 1987).

For Stone and Hart (2019), “The process of making meaning out of the object contributes to the social formation of our practices, ourselves, and our world” (p. 23). The second-generation model of CHAT (Figure 9) adds sociocultural elements, such as other humans and the division of labour, to the analysis. Engeström’s Rules regulate activity and can be implicit or explicit (a curriculum is an example of an explicit mediating rule that a teacher must follow, while manners in a class setting are implicit). The Community is the cultural group to which the Subject belong – the Community ties could be a professional affiliation, such as science teachers who work in a school. The Division of Labor is the continuously negotiated distribution of tasks (horizontal) and power (vertical). A horizontal distribution disperses teachers' course loads within a school. At the same time, the vertical division of labour is found in the school structure, where teachers instruct, and administrators manage logistics and personnel.

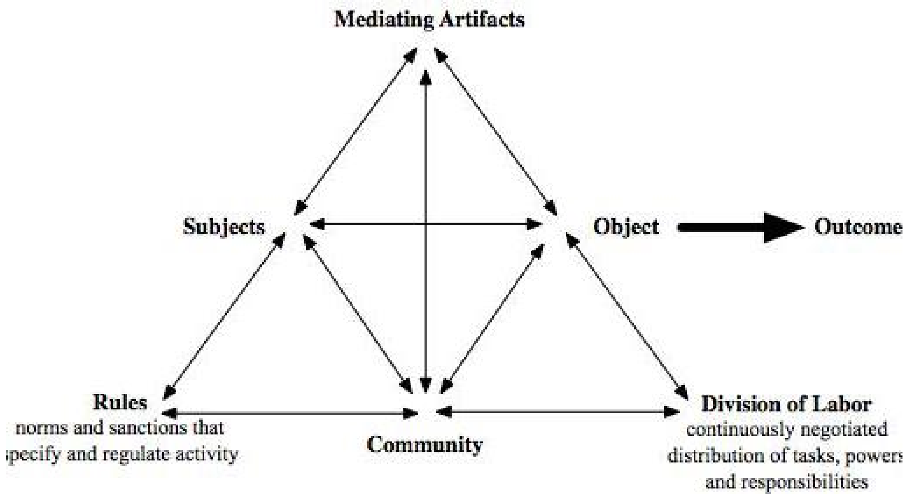

Figure 9. A second-generation activity system, Engeström (1987)

As a unit of analysis, CHAT demonstrates the multi-voicedness of activity, the historicity of activity, contradictions as driving forces of change in activity, and expansive cycles as a possible form of transformation in activity (Engeström, 2001). For example, when two activity systems work towards the same object, such as the activity of teachers in different schools towards the $Object_1$ of teaching via student inquiry, the outcomes as $Object_2$ (See Figure 10) may overlap during communication, such as a focus group or via an email conversation that results in education innovation, $Object_3$. This interaction that produces a new shared object is termed a third-generation activity system (Figure 10, Engeström, 2001). The expansive learning that results from the new shared object is examined in the subsequent section.

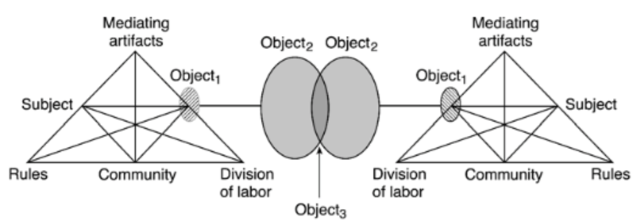

Figure 10. Activity Theory Diagram Expansive Learning (Engeström, 2001)

Expansive learning and the zone of proximal development

The theory of expansive learning concentrates on learning processes in which the very subject of learning is transformed from an individual to a collective activity system or a network of activity systems (Engeström, 2001). According to Engeström and Sannino (2010):

> …the theory of expansive learning must rely on its own metaphor: expansion. The core idea is qualitatively different from both acquisition and participation. In expansive learning, learners learn something that is not yet there. In other words, the learners construct a new object and concept for their collective activity and implement this new object and concept in practice" (p. 2).

An explicit example of expansive learning is the Change Laboratory, an intervention designed to generate expansion by establishing a context with actions and operations that facilitate the construction of a new object (Engeström, 2016). The Change Laboratory intervention requires knowing the context for learning and is initiated with a stimulus:

> The Change Laboratory is built on ethnographic data from the activity setting in which it is conducted. Critical incidents, troubles and problems in the work practice are recorded and brought into Change Laboratory sessions to serve as first stimuli. This "mirror material" is used to stimulate involvement, analysis and collaborative design efforts among the participants. (p. 30)

Engeström and Sannino (2011) conducted a change laboratory analysis of municipal home care in Helsinki, Finland, that sought to identify contradictions through the discursive manifestations of contradictions (contradictions are defined below). Their analysis sought findings through the analysis of "rudimentary linguistic cues that potentially express discursive manifestations of contradictions" (p. 370). Within a social learning activity, expansive learning "is an activity-producing activity" (Engeström, 1987, p. 125). However, expansive learning is not the province of the Change Laboratory. In a review of the expansive learning process of connected networks and individuals, it is possible to map learning from the zone of proximal development to the new model:

> Initially individuals begin to question the existing order and logic of their activity. As more actors join in, a collaborative analysis and modeling of the zone of proximal development are initiated and carried out. Eventually, the learning effort of implementing a new model of the activity encompasses all members and elements of the collective activity system. (Engeström and Sannino, 2011, p. 6)

The zone of proximal development factors in the developmental changes during expansive learning; a response to contradictions (Engeström, 1987, 2016). Vygotsky (1978) conceptualized the zone of proximal development as "the distance between the actual developmental level is determined by independent problem-solving, and the level of potential development is determined through problem-solving under adult guidance or in collaboration with more capable peers" (p. 86). However, contradictions are often linked to the new model within an activity system (Engeström and Sannino, 2011) and these may change activity.

Contradictions

According to Engeström (2016), "expansive learning sees the mechanism of transition in the stepwise evolution of contradictions inherent in the object of learning – that is, in the activity that is being transformed." (p. 27). To Engeström and Sannino (2011), "The elements of a dialectical contradiction relate to each other within the moving structure, historically. A dialectical contradiction refers to a unity of opposites, opposite forces or tendencies within such a moving system (p. 370). During the phases of expansive learning, there are four types of potential contradictions (Table 3) within or between the nodes of the activity system (Figures 8 & 9).

Table 3.

Contradictions, location and the result as actions (Engeström, 2016, p. 27)

Type of contradiction	Location	Resulting Actions
Primary	Within a node of the activity system (ex. within Subject or Rules).	Questioning the first learning action.
Secondary	Between two or more nodes (ex. between Subject and Rules).	These generate learning actions and modeling or examining the model.
Tertiary	Between a new mode of activity and the existing mode of activity.	Implementation of new activity and reflection
Quaternary	Between newly organized activity and neighbouring activity systems (see Figure 10)	Consolidation

"As contradictions are historically emergent and systemic phenomena, in empirical studies we have no direct access to them. Contradictions must therefore be approached through their manifestations." (Engeström & Sannino, 2011, p. 371). However, within expansive learning, contradictions may be a driving force that supports "the emerging new object" (Engestrom, 2016, p. 27). The following section employs examples of research from Newfoundland and Labrador context to clarify contradictions and manifestations.

Examples of local studies with contradictions.

Several local investigations of remote and face-to-face teachers employed a CHAT lens to study teacher learning. For example, Goodnough (2016) studied K-6 teachers who wanted to increase student engagement in STEM using inquiry lessons. During cycles of action research, the teachers' questioning produced manifestations indicative of contradictions. The manifestation was the challenge many teachers faced when they initially used new inquiry techniques for instruction. This was a manifestation of a primary contradiction as "the teachers in doing things in new ways, which resulted in changes in their thinking and practice" (2016, p. 760). Murphy and Rodriguez-Manzanares (2009) examined 13 e-teachers from CDLI who transitioned from face-to-face teaching to e-teaching. The teaching context change resulted in multiple contradictions for the teachers as "no one had a roadmap to follow, nobody had firmly established their routine" (p. 9). New tools, new rules, a new community and a modified division of labour conflicted with "sage on the stage" where the teacher was the knowledge source (a secondary contradiction). For example, the new remote-tools resulted in an instruction manifestation stated by a teacher, "We're not getting feedback, the facial expressions; you're not reading the signals from students that indicate lack of comprehension or boredom." (p. 10). The resolution of this node-to-node contradiction was e-learning instructional improvement, an "expansion of the object of the activity system involved in the learning effort." (Engeström, 2016, p. 7).

Connecting the literature theme

Within the PCK review I noted that learning contextual factors connect to and through pPCK to ePCK and may "serve to both amplify or filter each teacher's knowledge and skills to mediate teacher's actions" (Carlson et al., 2019, p. 88) – personal knowledge mediates actions. Within the inquiry review the context of the form of inquiry, from guided to open (Banchi & Bell, 2008; Blanchard et al., 2010), influence instruction, impacting the knowledge used to mediate teacher and student actions. And finally, the psychological tools and contradictions within activity (Engeström and Sannino (2011) mediate teaching and may produce expansive learning. The subsequent manuscripts will expand on this theme to reveal teacher learning as ePCK as mediated by LS (Chapter 2), examine the remote science inquiry product of LS (Chapter 3), and conduct activity theory analysis of mediation, contradictions, and expansive learning during LS teacher inquiry (Chapter 4).

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Chapter 2 - Changes in High School Distance Education Science Teachers' Pedagogical Content Knowledge (PCK) During Remote Lesson Study

Patrick R. Wells, Karen Goodnough, Saiqa Azam, and Gerald Galway

Abstract

This qualitative case study examines changes in Pedagogical Content Knowledge (PCK) of experienced distance education science teachers as they conducted a remote lesson study (LS). A three-teacher LS group, supported by a knowledgeable other (a retired teacher), developed a remote science inquiry instruction (RSII) lesson for distance education students. During LS's Study, Plan, Teach, and Reflect phases, teacher-enacted PCK (ePCK) was conceptualized using the Refined Consensus Model (Carlson et al., 2019). ePCK is defined as the "specific knowledge and skills utilized by an individual teacher in a particular setting, with a particular student or group of students, with the goal for those students to learn a particular concept, collection of concepts, or a particular aspect of the discipline" (p. 83-84). The remote LS context for Study, Plan, and Reflect was Google Meet, while the Teach phase occurred in Brightspace. The phase of LS impacted the ePCK engaged and developed. During Study and Plan, teachers studied curriculum outcomes, increased content knowledge, practiced data collection skills, and created an untested inquiry lesson with support documents. During the Teach phase, the lesson was tested and during online class interactions teachers applied knowledge of graph troubleshooting, produced adaptations for supporting students without apparatus, and revealed student graphing misconceptions. Teaching concretized the ePCK from the Study and Plan phases, and this knowledge was reinforced in the remote discussions of the Reflect phase. Despite the remote context, the LS facilitated collaborative learning during the planning and allowed meaningful

reflection in lesson debrief sessions, which developed ePCK skills and knowledge that improved remote instruction.

Introduction

COVID-19 placed many teachers in novel remote contexts for their teaching and professional learning (PL) (Calleja & Camilleri, 2021). While lesson study (LS) has a long history of effective face-to-face collaborative PL (Lewis et al., 2006), remote LS has comparatively fewer investigations (Calleja & Camilleri, 2021; Holden, 2023; Huang et al., 2021; Widjaja et al., 2021). In a comprehensive review, Huang et al. (2021) reported remote LS to be effective with some varied teaching and learning benefits; there are few studies of remote high school science LS. This study helps to address this gap and examines high school teacher pedagogical content knowledge (PCK) during LS, where the research lesson used remote science inquiry instruction (RSII). RSII differs from remote labs where equipment is remotely manipulated online (deJong et al., 2014) or simulations that have no physical apparatus (Price et al., 2019) as teachers remotely guide students, who are in multiple distance education contexts, to physically set up and manipulate apparatus and conduct an inquiry while synchronously connected to teachers in Brightspace (https://www.d2l.com). Lesson study, as an extended form of PL, should support the enactment of student-inquiry instruction (Miranda & Damico, 2015). To clarify the depth of challenges and potential rewards of remote LS for RSII, we now delve into science inquiry literature, the benefits of LS, and teacher PCK.

Literature Review

Science Inquiry Benefits and Challenges

The Next Generation Science Standards (NGSS) Science and Engineering Practices (https://www.nextgenscience.org/) and the Integrated Skills Unit (NLDE, 2018) require teachers to provide students with scientific inquiry experiences. The emphasis is logical; inquiry reportedly increases student achievement, intrinsic motivation, and performance on high stakes tests (Blanchard et al., 2010; Saunders-Stewart et al., 2012). DiBiase and MacDonald (2015) found that inquiry-based instruction engaged students; more than the passive learning style found in traditional lessons - likely a result of inquiry positioning students at the center of their learning (Blanchard et al., 2010). In remote contexts, conducting an inquiry may benefit students by experiencing tangible results and sensory feedback while they use equipment and collect data (Faulconer & Gruss, 2018). However, inquiry instruction is challenging for both novice and experienced teachers (Capps et al., 2016), perhaps, due to the diverse workloads versus teacher-centered classes (Harris & Rooks, 2010). Managing an inquiry class or a lab is reportedly more "complicated and messy" than a teacher-centered instruction (Neumann, 2013, p. 172), and students unfamiliar with inquiry may experience difficulties (Donnelly et al., 2014).

Remote teaching is technology-dependent, and while Zacharia et al. (2015) reviewed a trove of useful guidance techniques for virtual and remote labs, the teachers of our investigation were in different remote contexts than their students. Offering support requires a teacher to sense a need for guidance. In face-to-face classes, *noticing* is the ability of teachers to make sense and manage the "ongoing information which they are presented during instruction" (Sherin & Jacobs, 2011, p. 5); a learned teacher skill that improves with experience (Chan et al., 2021). How the teachers of this study sensed their students' needs or misconceptions was addressed during the Plan phase of remote lesson study.

Lesson Study

During LS, teachers collaboratively engage with a research lesson using a four-phase cyclical process: (1) studying curriculum and formulating goals, (2) planning the lesson, (3) conducting the research lesson for others, and (4) reflection to consolidate learning and for another participant to present the same lesson (Lewis et al., 2006; Wong & Cheung, 2014). The rise in LS popularity may be attributed to LS's focus on teaching versus teachers (Lewis et al., 2006), a student learning focus (Dudley, 2013), and collegial sharing of knowledge during LS cycles (Lewis et al., 2012). The "strong system of organizational learning routines" of LS facilitates improvements in teacher practice during curriculum change (Lewis & Takahashi, 2013, p. 214), helping teachers to become socialized into the act of improving teaching (Hiebert & Stigler 2017). Lewis et al. (2012) suggested LS focus on collaborative teaching contributes to collegial learning by connecting colleagues' practice and instructional resources. Remote LS, particularly in the remote high school science context, has yet to be investigated (Huang et al., 2021).

Teacher Knowledge and PCK with LS

LS develops the knowledge required to improve teaching (Allen et al., 2004; Dotger & McQuitty, 2014; Dudley, 2013). Preservice science teachers used LS to focus on inquiry tasks where they learned the important characteristics of inquiry and supports for student learning (Conceição et al., 2018). Lawrence and Chong (2010) reported that high school teachers' LS learning developed content knowledge and knowledge of students while improving pedagogical knowledge. Dudley (2013) found LS improved microteaching, enhanced understanding of K-12 students' learning needs, and improved student learning. Dudley also reported the examination of optimized pupil learning of LS requires knowledge of pedagogy, knowledge of curriculum, and knowledge of the pupil. Akerson et al. (2017) and Lampley et al. (2018) reported the impacts of LS on PCK of pre-service science teachers and science graduate teaching assistants respectively. Schipper et al. (2018) found that LS promoted adaptive teaching required for instruction of students of varied learning abilities using "differentiated lesson material or instructional strategies to address [the] learning needs and consequently prepare their lessons" (p. 115). While these studies demonstrated the effectiveness of LS, none, except Dudley (2013) and Lawrence and Chong (2010), explicitly examined science teachers' PCK components. Schipper et al. (2018) focused on teacher efficacy without mentioning other PCK components.

Currently, remote LS is a growth area primarily restricted to mathematics teaching (Calleja & Camilleri, 2021; Huang et al., 2021; Huang et al., 2023); however, many studies demonstrated positive teaching and learning effects (Allen et al., 2004; Dotger & McQuitty, 2014; Dudley, 2013; Lawrence and Chong, 2010). Recently, a new science teacher PCK model emerged from the teacher knowledge discourse that is compatible with the LS cycle (Carlson et al., 2019) and may better address nuanced science PCK elements versus math PCK and TPACK conceptualizations (Huang et al., 2021).

Conceptual Framework

Teacher PCK

Shulman (1986) first conceptualized PCK as a "missing paradigm" of knowing that separates a subject teacher from a subject area specialist by "going beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (p. 9). Since Shulman (1986), teacher researchers have refined categories of PCK (Chan & Hume, 2019), while building heuristic models based upon their research (Carlson et al, 2019; Gess-Newsome, 2015; Grossman, 1990; Magnusson et al., 1999; Park & Oliver, 2008). In the last decade members of the PCK discourse collaboratively developed two models - the Consensus Model (Gess-Newsome, 2015) and later, the Refined Consensus Model (RCM, Carlson et al., 2019).

The RCM conceptualized three forms of PCK: enacted PCK (ePCK), personal PCK (pPCK), and collective PCK (cPCK). PCK used in the practice of teaching is ePCK, defined as "the specific knowledge and skills utilized by an individual teacher in a particular setting, with a particular student or group of students, with the goal for those students to learn a particular concept, collection of concepts, or a particular aspect of the discipline." (p. 83-84). Enactment includes "knowledge and reasoning behind the act" as teachers plan, teach, and reflect with ePCK (p. 84). The model of ePCK (Figure 1) demonstrates the cycle of pedagogical reasoning that mirrors LS phases. The "knowledge of and reasoning behind the act of teaching when interacting directly with students" (p. 84) is reflection in action (RIA), while "the acts of planning instruction and reflecting on instruction in student outcomes" is reflection on action or ROA (p. 84). Pedagogical reasoning's decisions make ePCK visible as "teacher's expression of knowledge, choice of strategies and representations" (p. 85).

Personal PCK (pPCK) is "the cumulative and dynamic pedagogical content and skills of an individual teacher" collected during any personal learning experience (Carlson et al., 2019, p. 85). The arrows (Figure 1) represent the knowledge exchange between ePCK and pPCK that may be filtered or amplified through pedagogical reasoning (p. 85). A teacher's filters and amplifiers are personal - rooted in the teacher's beliefs and orientation and impact pedagogical decision making (Grossman, 1990; Magnusson et al., 1999). The context of pPCK includes any factor that connects to the learning environment, such as curriculum and individual student attributes (Carlson et al., 2019). Learning contextual factors, such as remote or face-to-face instruction, connect to and through pPCK to ePCK and may "serve to both amplify or filter each teacher's knowledge and skills to mediate teacher's actions" (p. 85). This layer of the model separates pPCK from cPCK (Figure 1).

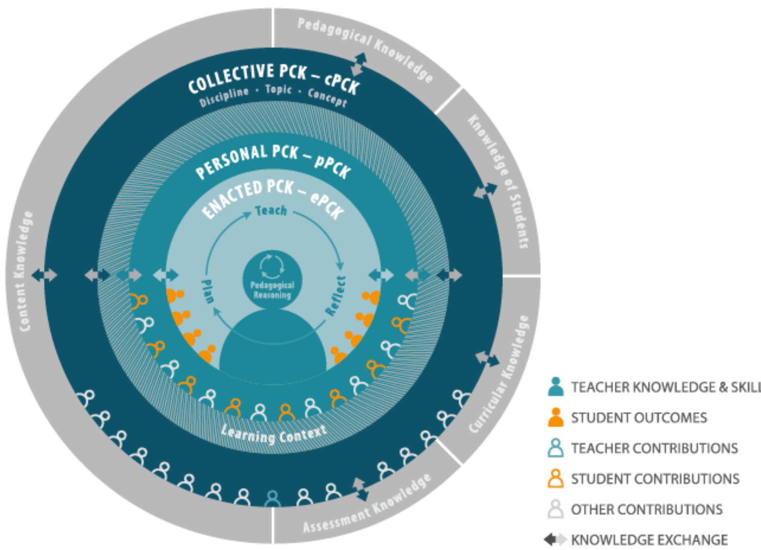

Figure 1. The Refined Consensus Model of PCK (Carlson et al., 2019).

Collective PCK, cPCK, is "an amalgam for multiple science educator's contributions including the teachers own contributions" and is considered public (p.88). The cPCK is surrounded by foundational knowledge bases for all forms of PCK: pedagogical knowledge, knowledge of students, curricular knowledge, assessment knowledge, and content knowledge (p. 91). The RCM addresses the grain size of PCK, from knowledge bases through the three levels of PCK.

Teacher ePCK for lesson preparation and dynamic student contact during lesson enactment can be used to conceptualize science teacher knowledge during remote LS and address the following research questions:

1. How can teacher ePCK develop during remote LS?

2. How does the phase of the LS cycle impact ePCK development?

Methodology

This is a remote naturalistic study (Merriam & Tisdell, 2016). Interpretive methods helped to understand the phenomenon through observation and interaction (Creswell, 2015), and this inductive investigation produced a descriptive account of the events during remote LS (Merriam & Tisdell, 2016). A case study is suitable for answering "how" and "why" questions without controlling behavioural events (Merriam, 1998). Merriam (1998) defines a case study as an intensive, holistic, descriptive qualitative analysis of a "single unit or bounded system" (p. 12). In this study, the LS group and the knowledgeable other are the *case* examined during remote LS activities.

Sampling

The LS participants are experienced remote teachers (Table 1). The first author and the two teachers formed the LS group that conducted much of the LS work; the knowledgeable other is a retired teacher and supported the research lesson development with technical and pedagogical advice.

Table 1.

Participant information.

Pseudonym	Diane	Norman	Paddy	Anthony
LS Position	Science Teacher	Science Teacher	Science Teacher/ Researcher	Knowledgeable Other

Years of Experience	17	21	28	30
Education	BSc., B.Ed., M.Ed. (in progress)	BSc., B.Ed., M.Ed.	B.Sc.H., M.Sc., B.Ed., Ph.D. Candidate	BSc., B.Ed. & M.Ed.
Gender	Female, white settler	Male, white settler	Male, white settler	Male, white settler

Research Stages and Protocols

The LS group members were separated by a minimum of 350 km and remote methods were necessary to meet university and school district ethical clearance. The synchronous PL, and subsequent LS meetings, were conducted using Google Meet. Google Docs, Screencastify, Jam Board, and Gmail were used for asynchronous collaboration and the research lesson was presented in Brightspace. The LS teacher research unfolded in two distinct stages over 16 weeks.

Stage 1 - PL, Study, and Plan

Weeks 1-3: The participants conducted a full-day PL for LS and inquiry instruction after pre-interviews. *Lesson Study: Step by Step* (Lewis and Hurd, 2011) and Mills College resources (www.lessonresearch.net) were the PL resources and the scientific inquiry PL examined the levels of inquiry from Banchi and Bell (2008).

Weeks 4-11: Seven synchronous one-hour sessions and asynchronous work. Two study meetings examined curriculum and course units. Five Plan sessions developed a research lesson that considered student thinking, scaffolds during remote inquiry, and instructional strategies.

Stage 2 - The Research Lesson – Teach and Reflect

Weeks 12 to16: During the LS Teach phase, Diane conducted the research lesson in Brightspace.

The LS group examined the recorded video lesson and conducted a post-lesson reflection (Reflect). Norman then re-taught the lesson, and the LS group, with the knowledgeable other, reviewed the lesson in a second post-lesson reflection (Reflect). Stage 2 concluded with semi-structured interviews.

Data

The case study data in Table 2 are of multiple types with varied collection methods, sources, and contexts (Leavy, 2017). All participant remote interactions were video recorded, and later, the data were shared with LS group members to ensure the participant's meanings were reflected in the case (internal validation - Cohen et al., 2016). Video recording of all remote interactions permitted the first author to concentrate on his role as a teacher in the LS group as field notes and coding were collected after meetings as opposed to during meetings.

Table 2.

Data sources by stage, type, and context.

Stage of Research	Type of Data	Context
Stages 1 & 2	Field notes	Google Meet for PL, LS meetings, remote student observations
Stage 1	LS PL session Study and Plan Meetings	LS Group in Google Meet
Stage 2	Reflect	Google Meet using lesson observations
Stages 1& 2	LS meeting running notes	Google doc of meeting proceedings
Stages 1 & 2	Research lesson plan and PL artefacts	Google Doc and Jam Board

Stage 2	Google Form reflections	Asynchronous submission
Stage 1 & 2	Semi-structured interviews	Google Meet

Coding and Analysis

Transcribed recordings, images, and text data were imported into MAXQDA and, initially, were examined using PCK codes from Goodnough et al. (2019) and *a priori* codes for remote LS (*Plan, Teach*, and *Reflect*) and inquiry instruction (*skill development* and *level of inquiry*). However, repeated reading of the data resulted in the creation of new codes for lesson remote study (*Remote collaboration* and *Logistics*) and the RCM Model (Carlson et al., 2019). The open coding (Strauss & Corbin, 1998) created PCK subcategories such as *formative assessment (predictions)*, *decision making in teaching (during the lesson)*, and *decision making in teaching (reflect)*. This hybrid strategy for coding (Blair, 2015), "helped develop a bottom-up device that reflects key concepts that were found in the participant data" (p. 26).

Limitations

We recognize that qualitative inquiry is subjective and the "intent of qualitative researchers to promote a subjective research paradigm is a given" (Stake, 1995, p. 45). We do not claim to take an objective position and understand that the first author's presence and active participation in all the LS processes may influence each teacher's situation and the LS group (Pring, 2015). To mitigate these potential influences, the roles of meeting leader, time manager, and note taker were rotated for each LS meeting to distribute leadership among group members.

Results

The remote LS demonstrated that ePCK used and developed varied by LS phase.

Therefore, the findings are presented by LS phase to demonstrate the contextual impact on ePCK engaged and developed.

Study

Teacher Amplifiers and Curriculum Knowledge

The LS group members, which included the first author as a full participant, were interested in conducting activities as a long-term goal for student learning and skill development. Pre-interviews and teacher comments during PL revealed Diane and Norman used confirmation and structured inquiry (Banchi & Bell, 2008) and in Study, both teachers activated personal amplifiers for conducting inquiry. Diane believed inquiry activities make science "come alive" and "brings science out of the textbook", while Norman believed "teaching is engaging your audience and entertaining" and that activities are, "extremely important."

Later in Study, review of the curriculum revealed Diana, Norman, and Anthony were not fully versed with the new Integrated Skills Unit of the Science curriculum (NLEECD, 2018). Norman's stated, "I would say a medium level" when asked about the Skills Unit. This curriculum was published after Anthony retired and, for Diane and Norman, this was their first use of the curriculum. Thus, the first remote Study meeting, increased teachers' ePCK for aspects of curriculum.

In the second Study meeting, both Diane and Norman indicated they wanted to conduct a remote activity using Vernier® interface and probes. The negotiations required to determine the unit of study and demonstrated Diane's desire for skill development.

> Norman: If we want to go the ecology route… we have a pH sensor … But, with the motion sensor, I think it's got to be acceleration.

Paddy: How comfortable are you putting that lab off …to prepare for the acceleration lab?

Norman: …Diane, are you comfortable with it?

Diane: I mean, I've never done it… Most times the kids are given data and said, "Go and graph it." … my learning curve to actually use [Vernier], to do it, would be huge.

Following 20 minutes of negotiation, the teachers committed to focus on the Motion Unit.

Plan

Testing the Equipment and Student Concerns

The first Plan meeting started with the three-member LS group assembling equipment and connecting sensors to interfaces. In short order, each LS group member collected motion data and practiced the skills needed to support students conducting motion activities (new for Diane). In Google Meet, Norman and Paddy noticed a graph shape did not match the motion.

Paddy: So, what shape are you trying to make?

Diane: The last one. [a distance-time graph]

Norman: That was pretty close, except the spike at the end.

The unexpected graphs pushed Norman and Paddy to explain the motion and this discussion paid dividends for Diane, gaining content knowledge of velocity/time and distance/time graphs and shapes for several types of motion. Further curriculum review revealed activities, such as determining instantaneous velocity, were also described in the textbook (new ePCK for Paddy).

Norman expressed concerns about RSII in Brightspace, "It's a whole different thing trying to get things to work … and you're not there to hands-on do the things with them and guide them… it's not as easy as if you actually had them in front of you". The LS group collectively decided the students in remote sites required an equipment guide. The LS group delegated Paddy to develop an asynchronous support Google doc with images and videos (https://docs.google.com/document/d/1hAxZAg_ZYkQL7RZGF_lOQiVdCXRGX2JakhIYE2bzf0o/edit?usp=share_link), like the videos of Maguire et al. (2010). Norman and Diane focused on lesson selection and critical review of the asynchronous support Google Doc.

The Research Lesson, Student Needs, and Norman's Orientation

The subsequent Plan meeting started with Norman suggesting the students examine, "position-time graphs for accelerated motion… it's determining instantaneous velocity using tangents." Diane piped in, "[page] 246 is the start of the section." Norman responded, "If we can get them to make some sort of a curve that was reasonable with the motion detector…they should be able to print off their graph… to calculate instantaneous velocity." Diane wondered, "Are we going to develop a handout for them?" This concern spurred the development of a lab Google doc that would change significantly (mainly asynchronously) before it was shared with the students. Norman spoke up, demonstrating an inquiry filter, "I'm going to have the whole thing done with examples…so they know what they're doing, is just going to be an experiment to try and recreate it." This statement demonstrates Norman's preference for confirmation inquiry. Norman mentioned student challenges for drawing the slope tangent line on the graph, "Even getting that idea, pick a spot and then draw a line that only touches once."

RSII assumes that Diane and Norman in Brightspace, are the primary student supports. The CDLI remote students would have no coaching from an on-site teacher, although a teacher is assigned to supervise, not teach, students at each distance education school site. Diane said, "It's going to be independent. We're going to be the problem solvers." Norman believed the students with remote support will have difficulties, "If we have step-by-step instructions… they're going to have a hard time." These concerns focused LS group work on resources and strategies, such as a practice activity, to support the students.

Diane's Practice Activity and Curriculum Mapping

Diane was the Plan meeting leader and started with a report, "I've had one class do sets of graphing in which they did six graphs for me; and all I gave them was – OK, make a graph." A week earlier the asynchronous support Google doc was shared with the students, and clearly, the students learned to successfully assemble the equipment, allowing Diane to conduct her first practice activity. Diane's remote practice, and her troubleshooting, were her first thinking in action and increased her knowledge of skill instruction while reinforcing her kinematics content knowledge. Diane was innovative and included remote students without equipment. Synchronously in Brightspace, the remote students watched Diane's video feed and directed her using chat to move with a motion sensor to make specific distance/time graphs (simultaneously visible with application sharing).

Later, Diane reminded the LS group, "…we needed to go through the curriculum guide and decide what ones [outcomes] we're actually targeting [in the] lesson." The LS group collectively reviewed the Integrated Skills Unit outcomes and then focused on predictions.

> Norman: I don't think we'll make them do a hypothesis. I don't know. Do you want to do it?
>
> Diane: Well…
>
> Paddy: Prediction is useful…shape of the graph … what should it look like?
>
> Diane: Keep the prediction. I usually with the labs, I do predictions.

Diane demonstrated an important inquiry ePCK amplifier when expressing that predictions are vital for conducting a student inquiry. Reflecting on the practice activity and examining the skill curriculum outcomes, the LS group found 13 outcomes in the research lesson, such as, “state prediction and hypothesis based on available evidence and background information.” (NLDE, 2018, p. 29). When students set up and use the interface they address “Use instruments effectively and accurately for collecting data.” (p. 29). This Plan meeting and finding Skill outcomes, demonstrates newly acquired ePCK for curriculum.

Diane’s Structured Inquiry and Seeing Student Predictions

In the Plan meeting before Diane presented the research lesson, she said, “I'm going to use this as the intro into acceleration…versus a follow-up activity” (meaning a structured inquiry). Diane affirmed the lab document required graphical predictions and provided a space for drawing one. The LS group reviewed the student lab Google Doc; the objective was to have instructions to guide data collection, and Diane’s expectations were, “Just get them through setting it up and getting a couple of good graphs…the follow-up will come after that.” The LS group discussed viable options for synchronous viewing of student predictions and inspecting graphs, including application sharing, screenshots, and student emails.

Teach

Diane Enacts the Research Lesson

Diane’s Brightspace enactment started with student check-ins with students at five remote sites to determine equipment status. Surprisingly, she found that all students had successfully assembled the apparatus in their remote context before the class started. Following a 5-minute introduction of distance-time graphs, the students were asked to make a graphic prediction for the motion of an object rolling down an inclined plane. The students seemed hesitant – not offering their predictions on the shared white board. Diane reminded the students of personal experiences like tobogganing and riding a bike downhill, then asked, “What happens?” A student added a comment to the public chat, “It picks up speed!” Diane confirmed, “This type of motion is termed acceleration!” During the predictions phase of the lesson all students made predictions, and two students drew straight lines on the shared whiteboard, indicating a misconception for graphing acceleration.

Before starting data collection, Diane reminded the students about the experimental error, “Think about what may make the data go strange … anything that may be a source of error.” The class groups in five remote locations started data collection and frenetic activity ensued – several students sent questions via chat, a group of students without equipment worked directly with Diane, and other students at remote sites started collecting motion data and sending results.

The students without equipment used the chat to guide Diane in collecting their data. Simultaneously, Diane checked other locations to ensure they were collecting data and examined their graphical results using Brightspace application sharing. For each acceleration curve Diane provided feedback, “That’s a good curve!” A common student chat question was, “What are the spikes in the graph?” Diane explained the spike was a change in velocity resulting from the object dropping off the inclined plane. After thirty minutes of this type of activity, Diane had applied her new ePCK developed during Plan, and all the students had data, with graphs, demonstrating acceleration on an inclined plane.

Reflect

Confirming Study and Plan Thinking on Action and the Practice Requirement

The Reflect meeting focused on small lesson details as the Study and Plan sessions predicted many students' problems. There were questions about the angle of the motion detector and setting up the apparatus on the floor versus a table – to avoid graph spikes. Norman suggested, “they would actually get a better result with it because it would actually keep rolling along the floor.”

Norman enjoyed watching Diane instruct, “I never watched anybody else's recording of class before, only my own.” Remote CDLI teachers rarely use video and Norman referenced Diane’s demonstration of the apparatus, “It was just interesting seeing that you had the video.” The LS group agreed the method of observing student predictions drawn on the shared white board, was useful for finding misconceptions although Diane stated, “we actually have never done it in class [referring to graph shapes]. So, this was their introduction.” This may explain why only two students made public predictions. The discussion continued:

> Paddy: They make a prediction and then screw it up, the memory they make from that is stronger. I mean, where do you guys sit on that?
>
> Norman: I would think the same thing…you learn more when you make mistakes.
>
> Diane: Yeah!

Two weeks later, Diane reviewed the students’ predictions in their labs and reported many graphing misconceptions – setting the stage for formative assessment.

The asynchronous support Google doc, and prior practice, were confirmed as vital for student data collection success. Before Diane started RSSI, check-ins revealed the students were ready, a student messaged, “Miss, we're all set up!” Practice during Plan taught Diane to support student learning during the research lesson and improved engagement. In the past, Diane had to coerce students to get involved with class but there was high engagement during the activity, and she reasoned, “I think it's just the fun aspect of it… it's putting that practical experience in their hands.” The remote students collected materials, built an inclined plane, set up the data collection devices, collected data, and reported their results. Further, the activity engaged students with many curriculum outcomes, local and NGSS, making RSII meaningful instruction.

Teach

Norman’s confirmation inquiry

In Brightspace, Norman retaught the research lesson with slight apparatus changes. For confirmation inquiry, he reminded students of the motion expected and then asked students for a hypothesis. Misconceptions were evident in student graphical predictions on the virtual whiteboard. One was the correct curved line depicting the acceleration with increasing slope over time, the other seven had straight lines; two with negative slopes and the other five had positive slopes.

Norman suggested that students examine their apparatus and procedures for error when reviewing the experiment. Like Diane, Norman supported students who did not have lab equipment, and once the activity started, he was troubleshooting a motion sensor for one group and supplying a demonstration of graphing to others. A student commented in the chat, “The car crashed at the end creating spiky data on the curve.” Norman, reflecting in action saying, “everything stopped” referring to the rapid velocity change at the end of the ramp. While helping several students at home without access to equipment, Norman checked on others at the remote school sites, “Did you get data?” “That’s a good shape!” The lesson showed high student engagement, and once again, all students completed the activity with the data required for their lab report.

Reflect

LS group and knowledgeable other

The LS group and Anthony reviewed the second research lesson and agreed student motivation was high. Norman reported, “there were groups of mine who basically had the whole thing hooked up before I even had it shown on the screen.” – indicating the effectiveness of the support Google doc.

Student misconceptions were discussed, and Paddy asked, “How important do you think getting them to make that prediction was?” Norman replied, “There's a certain complacency and getting them to start off. By making the prediction, gets them in the mind to start thinking about what they're doing.” Misconceptions were found in seven out of eight student predictions, and Norman was surprised that, despite his review, they did not make better predictions. When asked by Anthony about future RSII modifications, Norman confirmed teacher learning, “Having better preparation on the students' end … to get them familiarized with the equipment and how it will work…that saved a lot of headaches.” This validates how teaching reinforced the need for practice before the research lesson.

Summary

The results address the research questions as the teachers developed ePCK during remote LS and the phase of the LS cycle impacted ePCK development. However, ePCK development varied by participant and LS phase (Table 3). In the Study and Plan phases, LS group members engaged existing ePCK during reflection on previous experiences and developed ePCK by reflection in action (RIA) during laboratory equipment practice. Norman, Diane, and Anthony expanded their knowledge of curriculum. The focus on student's needs, such as technical support and student misconceptions, revealed teacher amplifiers during research lesson development, such as requiring student predictions, and filters like Norman's decision to use confirmation inquiry. The Study and Plan phases were preoccupied with remote teaching challenges evidenced through the development of the asynchronous support Google doc, along with a Google Doc student lab, and data collection contingency plans.

Table 3.

New ePCK by Phase of LS (KC-knowledge of curriculum, KA-assessment knowledge, KS-knowledge of students, KI - knowledge of instruction, CK-content knowledge, F-filters, Amp-amplifiers, RIA-Reflection in Action, ROA-Reflection on Action).

Teacher	**Study - ROA**	**Plan- ROA**	**Teach and Re-teach - RIA**	**Reflect - ROA**
Diane	KC Amp-decision making	KC Amp-decision making, structured inquiry KA-formative assessment KI-practice (RIA) KS-needs, learning difficulties, & motivation CK-motion	KA- formative assessment KI-conducting RSII KS- motivation, misconceptions, & needs	KS-misconceptions & needs
Norman	KC Amp-decision making	KC F-decision making, confirmation inquiry KA-formative assessment KI-practice (RIA) KS-needs, learning difficulties, & motivation	KA-formative assessment KI-conducting RSII KS- motivation, misconceptions, & needs	KS-misconceptions & needs
Paddy		KC-textbook outcomes KI-practice (RIA)	(ROA) KI-RSII	KS- misconceptions & needs

	KS-needs, learning difficulties, & motivation	

The Teach phase involved teacher/student interactions was RIA, and galvanized prospective ePCK elements developed through the reflection on action (ROA) during Study and Plan. For example, requiring student predictions to expose motion misconceptions reinforced the use of this formative assessment strategy. Also, Diane and Norman used RIA during the lesson to support data collection for students without equipment while simultaneously assessing other students' graphs observed with application sharing.

Finally, in the Reflect phase for two lessons, the discussion of teachers' lived experience fortified participant's ePCK for misconceptions and student technological needs; both recognized as fundamental research lesson components.

Discussion

The LS cycle conducted remotely (Huang et al., 2021, Huang et al., 2023), or in person (Lewis & Takahashi, 2013), emulates the RCM "Plan-Teach-Reflect" connected with pedagogical reasoning for teacher knowledge (Carlson, et al., 2019). This harmony of structure helps to isolate teacher learning during planning and teaching, supporting the study of teacher knowledge. According to Baxter and Lederman (1999), "PCK is both an external and internal construct, as it is constituted by what a teacher knows, what the teacher does, and the reasons for the teacher's action." (p. 158). Remote LS, specifically the Study and Plan meetings, revealed teacher's ePCK, or what they know, while developing research lesson – their best lesson without student outcomes (Carlson, et al., 2019). Lesson enactment during the Teach, showed teachers' actions - applied skill and knowledge, actions that at times required quick “thinking in action” to respond to support student learning. Finally, in a uniquely remote Reflect, teacher observations of class recordings, and perhaps asynchronous observer vicarious learning (Voit & Drury, 2006), produced discussions that focused on strategies that resulted in student accomplishments – such as equipment practice and asynchronous student learning from Google Docs.

The Study and Plan LS activities effectively revealed teacher amplifiers and filters, engaging teachers’ beliefs (Van Driel & Berry, 2012) for pedagogical decisions such as the choice of lesson and type of inquiry; either structured or confirmation (Banchi & Bell, 2008). The teacher ePCK for curriculum was limited in Study and developed through application and mapping in Plan. Interestingly, once the curriculum was specified, it was not discussed again though it was evident in the RSII as a product of ePCK in Plan. Learning topic-specific knowledge of motion on an inclined plane started in Study and Plan, as predictions of student difficulties for graphing motion (Tairab & Khalaf Al-Naqbi, 2004). This ePCK completed its development as teacher knowledge of students (KS, Table 3) when student misconceptions of several forms, were observed during the Teach phase. The student graph predictions or “student outcomes” (Carlson, et al., 2019, p. 84) are feedback (Dudley, 2013), termed “Psychic rewards” by Lortie (1975), and are used to decide to keep, modify, or discard a teaching strategy such as a prediction.

The examination of math teachers PCK for knowledge of teaching, along with knowledge of content and students, showed a chronological evolution of dialogue over successive cycles of LS (Shúilleabháin, 2016). The LS phases from Plan to Teach, created feedback knowledge loops referenced by Dudley (2013) and concretized Diane and Norman’s prospective knowledge of the plan phase, during the enactment of Teach. Dudley's evidence, while from 9-year-old students, demonstrates that learning intimate details using student evidence will help teachers comprehend diverse individual needs. Further, misconceptions of the high school students of this study and others (Dial et al., 2009; Maguire et al., 2010), revealed student needs and misunderstanding that must be addressed through teacher planning and enactment - reinforcing the importance of teaching and re-teaching the lesson (Lewis et al., 2012), and teaching as a form of PL (Stigler & Hiebert, 1999).

The observed student misconceptions were discussed in Reflect and reinforced the ePCK of student misconceptions - demonstrating the importance of all remote LS phases in the progressive development of teacher knowledge (Lewis et al., 2012).

Within the PCK learning cycle of "Plan-Teach-Reflect" (Carlson, et al., 2019, p. 84), we posit the transformation of new PCK can occur through reflection in action or reflection on action (Carlson, et al., 2019, Park & Oliver, 2008). Repeated lesson enactment with data collection devices for kinematic inquiries will eventually make this instruction, and recognizing misconceptions, a tacit task or knowing in action (Schon, 1983). However, the initial enactment of the research lesson had at times, a "situation of uncertainty" and "uniqueness" (p. 50). While guiding RSII, the teachers received and evaluated multiple student outcomes, sent as graph images via application sharing, that required "reflection in action" (p. 51). Teaching remotely has less, and unique sensory inputs, compared to a face-to-face classroom. However, the RSII lesson purposefully provided opportunities for noticing (Criswell et al., 2021), when students shared images of their graphs and predictions. These images required "reflection in action" to find motion misconceptions and graph confusion, commonly found in students of this age (Tairab &

Khalaf Al-Naqbi, 2004). This noticing was important as addressing a student's misconceptions requires timely feedback (Dial et al., 2009). Misconceptions are student outcomes (Carlson, et al., 2019, p. 84) observed during teaching and were re-examined in the LS Reflect phase. Therefore, the students' outcomes (Carlson, et al., 2019) are important drivers of transforming and integrating new teacher knowledge during LS (Juhler, 2016; Maguire et al., 2010).

Conclusion

Science inquiry is a complex form of instruction (Capps et al., 2016), compounded by a remote context; nevertheless, remote technologies allowed for long term science experiences while teaching, crucial for teacher learning (Lotter et al., 2007). Remote LS meetings - Study, Plan, and Reflect - shared knowledge of the collective vital for learning of individual LS group members. The enactment of the Teach phase of LS, while remote, was contextually different than Study and Plan with detectable student outcomes, such as graphing misconceptions, that reinforced or modified teachers' ePCK through teaching. The findings of this case study underscore the importance remote collaborative planning (Lewis & Takahashi, 2013), predicting student behaviours (Lewis et al., 2006), experiencing remote lesson enactment, and shared reflection and learning from teaching experiences (Lewis et al., 2012), to develop ePCK and improve teaching, via teaching (Stigler & Hiebert, 1999).

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Chapter 3 - Remote Science Inquiry Instruction for Motion on an Inclined Plane

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Abstract

This case study examined distance education (DE) teachers using remote science inquiry instruction (RSII) to support a hands-on lab for motion on an inclined plane. The RSII lesson was developed as part of an online lesson study (Lewis & Hurd, 2011). The activities of the teachers and students, collectively the case, are reported by the phase of lesson study (LS). Student preparation was deemed paramount during the *Study* and *Plan* phases of the LS as the students, in disparate geographical locations without expert local support, would conduct a remotely supported hands-on inquiry. The students used Vernier® probes and interfaces during synchronous instruction and teacher support via Brightspace. A Google Doc, with hyperlinked Screencastify videos, was developed during the *Plan* phase to train students to use the probes required to conduct the inquiry. During the *Teach* phase of the LS, the teachers used the predict–observe–explain (POE) strategy of inquiry to engage students and elicit samples of student thinking (White & Gunstone, 1992). To *predict*, the students drew the shape of the graph and explained the reasoning behind their prediction. To *observe,* the students conducted the inclined plane inquiry and noted what happened as the motion data was collected and graphed. To *explain*, the students observed the graph to engage synchronously with their data and teachers. This allowed students and teachers to address misconceptions during the prediction stage. Keeping the students engaged, requiring them to predict the graph's shape, and providing

simultaneous data visualization of the phenomenon helped support the conceptual change process. This article examines how RSII helped students conduct the remote inquiry process to observe motion with simultaneous graphical production to support their kinematics learning.

Introduction

Instructional technology has changed since the early 1980s when computers and their thought-provoking software (Dickson, 1985) were introduced to K-12 classrooms. Present educational technology offers seemingly unlimited remote opportunities such as virtual labs and simulations (Price et al., 2019), real-time ecological observings such as Ocean Networks Canada (https://www.oceannetworks.ca), and distant physical laboratories where students can remotely manipulate experiments (de Jong et al., 2014). When computers were first being used in the classroom, Mokros (1985) examined the impact of computer-based labs on students developing motion graphing skills and found that “middle school students are quite capable of producing and explaining graphs of position and velocity” (p. 6). Our investigation seeks to describe a similar lab by conducting motion activities to examine graphical outputs, except the distance education (DE) teachers of this case study used Brightspace to communicate support to Grade 10 science students separated by distances of 50 km to 600 km.

Literature Review

The extensive body of literature that exists about remote labs and virtual labs has been reviewed by Heradio et al. (2016). In addition, Zacharia et al. (2015) wrote specialized reviews and guidance on remote and virtual labs, and Sauter et al. (2013) wrote about the instructional authenticity of these tools. Although remote and virtual labs are sometimes suggested as an alternative to hands-on laboratories (Heradio et al., 2016), virtual manipulatives are not the same as physical lab equipment (Olympiou & Zacharia, 2012). Our study examines the blended use of technology, physical apparatus, and synchronous remote teacher guidance to support a hands-on lab. When these three components are used together, a unique form of DE teaching is possible, called remote science inquiry instruction (RSII). In the high-school context, RSII is similar to remote laboratories and virtual laboratories. For example, with RSII, a teacher is generally present (Eslinger et al., 2008). Also, RSII may include different forms of collaboration (Sinha et al., 2015), and the teacher or simulation may provide support or feedback (Zacharia et al., 2015). Students may be cognitively and metacognitively engaged if the inquiry addresses a hypothesis or answers a question (Brinson, 2015, 2017).

The students included in this investigation were from remote schools. They were not working alone as a person might do in a home study lab (Kennepohl, 2013). In a home study lab, a university student might conduct "laboratory work off-campus on their own" using kits, kitchen science, self-directed field work, or a combination of these things (p. 674). The distinguishing features of an RSII inquiry are the hands-on requirement and the use of a web-based communication and application-sharing platform for synchronous communication. The participants in this case study used Brightspace. The pedagogy that informs RSII is situation-specific and contextually determined (Kim & Hannafin, 2004) for DE students in schools during a pandemic.

Since 2001, CDLI (https://www.cdli.ca) has been dedicated to "the development and delivery of senior high-school distance education programming to students attending high schools in rural, remote, and isolated regions of the province" (Centre for Distance Learning and Innovation, n.d.). Prior to COVID-19, science teachers at the Centre for Distance Learning and

Innovation (CDLI) have used similar instruction for over two decades (https://www.cdli.ca/about-us.html). Since 2001, CDLI equipped distance education schools in Newfoundland and Labrador with data toolboxes that included data collection devices used to conduct remote inquiry. However, this is the first case study that documents CDLI teachers using RSII with students.

The focus on scientific inquiry is a common thread in the literature about remote laboratories, virtual laboratories, and RSII. Hofstein and Lunneta (1982, 2003) reviewed the teaching benefits of the science lab. They specifically discussed inquiry empowering technologies, noting student benefits. "By using associated software, they can examine graphs of relationships generated in real time as the investigation progresses, and examine the same data in spreadsheets and in other visual representations" (Hofstein & Lunneta, 2003, p. 41). Yet, teachers may view inquiry-based instruction as a difficult paradox to solve as they seek to balance their desire to engage students in activities for skill development against a curriculum that emphasizes basic academic tasks (Loyens & Gijbels, 2008). Recent curriculum changes address the paradox by emphasizing the importance of scientific skills. In Newfoundland and Labrador, the context of this study, newly minted K-12 science curriculum (https://www.gov.nl.ca/education/k12/curriculum/guides/science/) includes an "Integrated Skills Unit." Further, the Next Generation Science Standards published by the National Research Council (NRC, 2012) state that science and engineering practices are an important dimension for science learning and:

> better explain and extend what is meant by "inquiry" in science and the range of cognitive, social, and physical practices that it requires. Students engage in practices to

build, deepen, and apply their knowledge of core ideas and cross-cutting concepts (https://www.nextgenscience.org/).

These curricular changes are supported by decades of empirical findings from inquiry instruction research (Hofstein & Lunneta, 2003; Minner et al., 2010). The reason that lab investigations are more engaging for students (DiBiase & MacDonald, 2015; Wilson et al., 2010) is likely that they position students at the centre of their learning during scientific investigation, and the role of teachers is to scaffold student learning (Minner et al., 2010; Zacharia et al., 2015). Inquiry is recognized as an inclusive form of pedagogy (Duran & Duran, 2004; Meyer et al., 2012; Meyer & Crawford, 2015). Certainly, inquiry is more inclusive and effective than lectures (Blanchard et al., 2013).

Research suggests that taking care of individual professional development and developing communities of professional learning are crucial for increasing the number and quality of high-school science inquiry lessons (Blanchard et al., 2013; Miranda & Damico, 2013, 2015). The RSII lesson of this investigation is the product of a 16-week LS (Lewis & Hurd, 2011). Our research focused on the actions of the teachers and students during the remote inquiry and the reflections of the teachers and other members of the LS group. This unique study addressed a literature gap by reporting situation-specific and contextual factors for a remote high-school science inquiry lesson. The RSII described in this study is a kinematics investigation that focuses on knowledge and skill outcomes from local provincial curriculum (Newfoundland and Labrador Department of Education, 2018). However, the "Motion on an Inclined Plane" inquiry also engages students with Next Generation Science Standards, science and engineering practices such as "Planning and Carrying Out Investigations" and "Analyzing and Interpreting

Data" (NRC, 2012). The remote inquiry, conducted by students and supported by DE teachers, was carefully orchestrated as a result of the LS processes. This included a requirement for student predictions prior to the remote inquiry, a strategy known as "predict-observe-explain" (White & Gunstone, 1992).

Theoretical framework: Predict-Observe-Explain

RSII employs remote technology to manage and support students as they collect data in their remote locations to answer inquiry questions. The RSII used in this study included one structured inquiry and one confirmation inquiry to examine motion on an inclined plane (Banchi & Bell, 2008). Confirmation inquiry confirms and known result, while in structured inquiry, "students investigate a teacher-presented question through a prescribed procedure" (p. 27). The students collected motion data in their remote contexts using the LabPro and Motion Sensor 2 from Vernier Inc. (https://www.vernier.com/). During the LS, the group decided the inquiry lesson would employ the predict–observe–explain (POE) strategy first developed by White and Gunstone (1992) and later popularized by Haysom and Bowen (2010).

Research about using POE has found that the technique helps unearth and address student misconceptions about factors such as circuits (Phanphech et al., 2019), force and motion (Kearney & Treagust, 2001), and colours of light (Keleş & Demirel, 2010). An early longitudinal investigation applied POE to a first-year undergraduate physics course. The course used qualitative conceptual problems and worked examples from the teacher (Searle & Gunstone, 1990), rather than the simulations and hands-on laboratories described above. The investigation reported initial success, although long-term conceptual change was not evident in their study group. For the student to cognitively engage with the concept of motion on an inclined plane, they need to predict the results of the experiment. The *predict* stage of POE is vital for students because it engages them in the research question and allows them through cognition to create an expression of their conception (Gunstone & Mitchell, 2005; White & Gunstone, 1992).

In our study, students were asked to predict the shape of the motion graph and provide reasoning for their prediction. Many other studies have reported that students experience challenges with kinematics graphing (Beichner, 1994; Kozhevnikov & Thornton, 2006; McDermott et al., 1987). Based on his 28 years of experience with high-school student inquiry, Patrick Wells, the first author of this case study, agrees with these findings. In the POE of this investigation, after their prediction, students conducted the inclined plane inquiry to *observe* the phenomenon and then *explain* the phenomenon they observed. Engaging students' prior knowledge during inquiry supports the social construction of knowledge (Colburn, 2000), and in a formal report, the students reconciled their predictions' differences and what happened.

Research Design and Methods

Case Study

This case study (Merriam, 1998) was an online interpretive inquiry (Merriam & Tisdell, 2015) of RSII. The case study examined developing and enacting a DE inquiry lesson developed during a 16-week remote lesson study (Wells et al., 2023). The boundaries of this holistic descriptive account were drawn around the three DE teachers and remote students.

Sampling and Contexts

The LS participants were two DE teachers purposefully sampled from the CDLI and the first author as a DE teacher and researcher (Table 1). To conduct synchronous instruction in remote geographic locations, we employed Brightspace (https://www.d2l.com). The number of remote school locations that joined synchronous science classes varied from seven to ten per class. Some remote schools had four to five students in a DE science class; others had two to three students and total class sizes varied from 18 to 22 students. Due to internet bandwidth issues in rural areas, instruction employed in Brightspace did not include continuous student camera connections with the teachers. However, all the students could see the teachers, share applications, and communicate by audio and through public and private chat.

The teachers referred to as the LS group, developed and conducted the remote inquiry as part of the LS cycle (Lewis & Hurd, 2011). Other participants supplied technical and logistical support to the LS and included: a retired CDLI teacher/administrator acting as a knowledgeable other, a CDLI administrator, the school principals from remote sites within the Newfoundland and Labrador English School District, and CDLI technical staff. Each remote class site also had a supervising teacher that managed the classroom but did not participate in instruction.

Table 1.
Participant Information

Pseudonym	Lesson Study Group Position	Teaching Experience	Education
Dianne	CDLI Remote Teacher	17 years	BSc, BEd, MEd (in progress)
Norman	CDLI Remote Teacher	21 years	BSc, BEd, MEd
Paddy (first author)	Researcher and Remote Teacher	28 years	BScH, MSc, BEd, PhD Candidate

Research Stages, Protocols, and Data Sources

Due to the COVID-19 pandemic, ethical clearance required remote research protocols. The geographically separated teachers communicated, collaborated, and held LS meetings using

Google Suite apps including Google Meet, Google Docs, and Gmail. The first four weeks of the investigation included professional learning related to LS and science inquiry instruction. The majority of the LS meetings were conducted using Google Meet. Asynchronous lesson development used Google Docs. Other communication for logistics and questions involved Gmail, Google Calendar, and text messages. The LS was completed within a 16-week timeframe (see Table 2).

Table 2.

Timeline, Activities, Interface/Context, and Data Sources Stage (*transcribed)

Timeline	Activities	Interface/Context	Data
Weeks 1 – 4	Pre-interviews, Professional learning for lesson study and inquiry-based instruction	Google Meet & Google Docs	Field notes, Google Meet recordings*, Shared Google Docs
Weeks 4 – 11	Study and Plan phases of online lesson study	Google Meet & Google Docs	Field notes, Google Meet recordings*, Shared Google Docs
Weeks 12 – 13	Teach phase of online lesson study	Brightspace	Field notes of teachers and students in Brightspace from recorded lesson observation
Weeks 12 – 15	Reflect phase of online lesson study	Google Meet & Google Docs	Field notes, Google Meet recordings*, Shared Google Docs
Week 16	Focus group and final interviews	Google Meet	Field notes, Google Meet recordings*

Note: Professional learning for lesson study was based on, *Lesson Study: Step by Step* (Lewis & Hurd, 2011) and Mills College online resources (www.lessonresearch.net).

Teacher research in developing the inquiry lesson was guided by the Mills College definition of the Study, Plan, Teach, and Reflect phases of LS (Figure 1). To complete the scientific inquiry aspect of professional learning for inquiry instruction, we examined the levels of inquiry depicted in Banchi and Bell (2008) and discussed the challenges and rewards of supporting remote student inquiry.

During the *Study* phase, teachers reviewed the science curriculum (Newfoundland and Labrador Department of Education, 2018) and discussed the long-term learning needs of the students. A seminal consideration was that DE students were not supervised by an in-school science teaching specialist. The meetings held during the *Plan* phase revolved around preparing the lesson and examining the "Integrated Skills Unit" (Newfoundland and Labrador Department of Education, 2018). During Plan sessions, the teachers considered the students' technical and inquiry learning needs and the training students needed to use data collection devices.

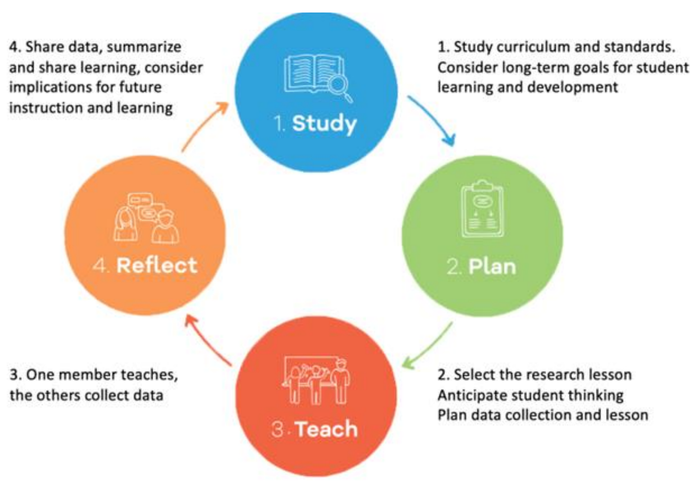

Figure 1. The lesson study cycle. Reprinted from The Lesson Study Group at Mills College (https://lessonresearch.net/resources/content-resources)

In the *Teach* phase of LS, the teachers conducted RSII using the research lesson and the developed resources, synchronously in Brightspace. Each lesson was video recorded, and the group members of the LS were given access to the lessons so they could make the lesson observations required for the *Reflect* phase. Dianne taught the lesson as a structured inquiry in which the students did not know the outcome of the lab (Banchi & Bell, 2008). After a reflection session, Norman re-taught the lesson as a confirmation inquiry in which students knew the outcome of the lab (Banchi & Bell, 2008). The second reflection conducted in Google Meet marked the end of the LS cycles. The research concluded with a focus group to discuss the importance of inquiry and teacher research as PL.

In case study research, triangulation contributes to internal validity (Merriam, 1998). The multiple types of data in Table 2 were gathered through various collection methods and from varied sources and contexts (Leavy, 2017). All data in this study were supplied to group members of the LS to ensure that the participant's meanings were reflected in the case. This fostered internal validation of data sources (Cohen et al., 2017).

Coding and Analysis

The field notes and lesson resources, along with the transcribed teacher interviews and meetings, were imported into MAXQDA to examine the lesson study activities of teachers and the student and teacher actions of the lesson during the Teach phase. The initial framework for coding included two a priori code categories: Lesson Study codes and RSII codes. It also included sub-codes such as Level of Inquiry, Lesson Study Plan, and Lesson Study Teach. During repeated reading while listening to the audio recordings, subcategories emerged such as Lesson Study Collaboration, RSII Equipment Needs, RSII Outcomes, and Student Success. The strategy of creating categories lead to some open coding (Strauss & Corbin, 1998). This reflexivity was examined by Blair (2015). Some of our analysis approaches involved using a top-down category template with open coding. We believe this approach "helped develop a bottom-up device that reflects key concepts that were found in the participant data" (p. 26).

Findings

The Context for a Remote Inquiry

The two DE teachers of this study, Dianne and Norman, taught Science 1206 to 21 remote DE schools. Both Dianne and Norman independently taught two classes of Science 1206 and connected synchronously with as many as seven different DE schools per class using Brightspace. The number of students per site ranged from two to five. While Dianne and Norman were synchronously connected to students with Brightspace, each DE school had a supervising teacher for the school's DE classroom. The supervising teacher could support student safety including pandemic protocols, class management, and computer issues. However, the supervising teacher was not responsible for science lesson content, nor were they expected to be specialists at teaching science. Therefore, the LS group presumed the DE students would rely on the online resources and the DE teachers for content and technical support during RSII.

Preparing for Remote Science Inquiry Instruction

Following a review of the curriculum and remaining course units, the LS group decided to conduct the "Motion on an Inclined Plane" lab as the research lesson. This decision started the Plan phase of LS, and the teachers started training on how to use the data collection equipment and software required by the research lesson. One teacher struggled with obtaining motion data, but the issue was resolved by consulting with the knowledgeable other who suggested the newest motion sensor should be used to conduct data collection for objects closer than 5.9 inches (15 cm). This event and ongoing practice using the correct sensor focused the LS on elements required to support RSII during the Teach phase of LS. In later Plan meetings, the teachers examined logistics, data collection training, troubleshooting, and the pedagogical decision to use POE. They began by examining the logistics and determining the status of school-based equipment.

Logistics

Each DE school had a CDLI Lab toolbox that included an interface, several types of probes, and the cables required to power and connect the interface to a computer. Figure 2 shows the toolbox components required for the RSII lesson, including the *rolly object* (a tin can or other object) to be procured by the students. Class surveys conducted by Dianne and Norman found most DE schools had toolboxes, but several toolboxes were missing the motion sensor. Dianne reported, “I've had the kids looking around, and I got a number of schools who don't have a motion detector in their toolboxes.” The DE school support promptly helped classes locate the missing items from their toolbox and CDLI staff supplied upgrades such as motion sensors to the schools. At each school there were desktop computers designated for DE with interface software and Google Chrome. As a result, all students could view shared lab documents, collect data, and analyze the results of the experiments. However, as Dianne reported, the version of the interface used at each school varied, “The newer kits have the LabQuest, some even have the LabQuest2!” The different versions of the interface created a student training issue that is discussed later.

As reported by Norman, the three main instructional challenges of RSII were “time limitations, getting everybody co-ordinated in ten different schools, all [with] different problems.” Questions asked by the LS group included: “Could this inquiry lab be completed in one class?” “Will troubleshooting interfere with important instructional activities such as providing feedback?” The group addressed these issues by planning asynchronous and synchronous student training.

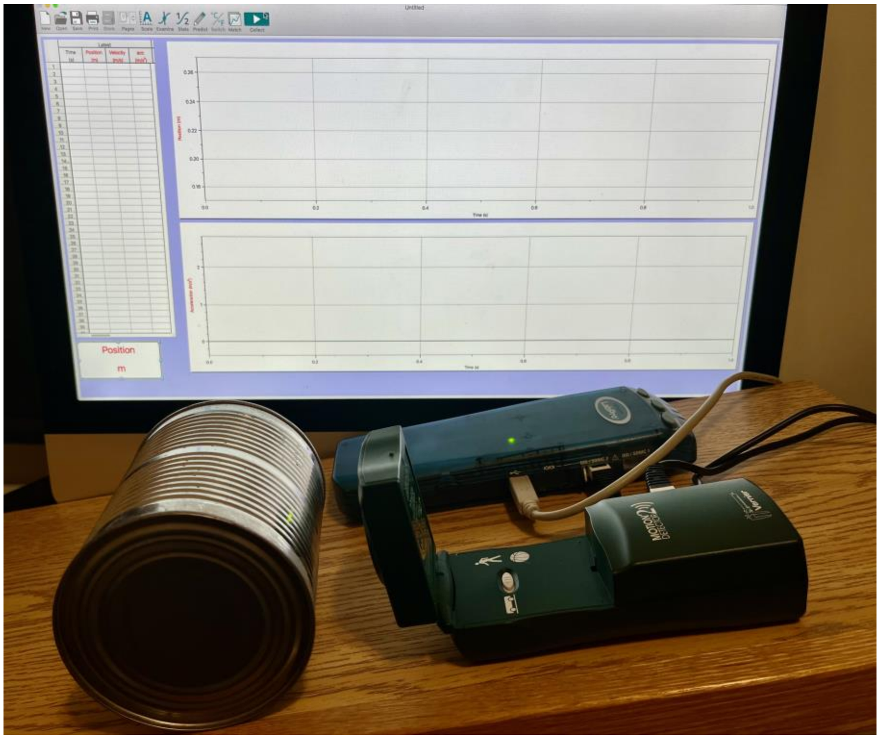

Figure 2. Apparatus for Motion on an Inclined Plane Inquiry. This apparatus for motion on an inclined plane inquiry that was used to measure the velocity of the can as it moved down the ramp away from the motion sensor (both in the foreground). The LabPro interface and monitor are in the background with the data collection software. As the can moved down the ramp (see Figure 5), a graph of motion was instantaneously produced.

Asynchronous Training

To address the issue caused by multiple versions of the interface, the LS group developed a Google Doc with images and text descriptions of the cables, sensors, and the three versions of the interface that might be used. They added hyperlinks to Screencastify videos that showed in detail the process used to connect each version of the interface with the sensor and the computer. People following this process benefited from watching the video and listening to the sounds produced by the interface or probe to indicate the current mode of function. For example, when the motion sensing probe was properly connected to the interface, the sensor produced a characteristic clicking sound.

The Google Doc and hyperlinked videos were the only asynchronous instructions provided to help students set up the data collection devices. Norman felt, “The biggest trick is going to be getting them to actually make the equipment function.” He then added, “You'd have to take a class almost where . . . you're making them get the equipment to function… [The] lab itself wouldn't take that much.” The teachers decided it would be worthwhile for the students to have a practice session in using the equipment before doing the lab activity and they set aside a class for this purpose.

Equipment Practice Activity and Evidence of Asynchronous Support

When the synchronous practice session started, most DE students had their equipment connected and turned on, ready to collect data. This showed the effectiveness of the asynchronous training document and hyperlinked Screencastify videos. The practice was a kinematic activity that required the students to create movement to mimic a distance-time graph. For example, students were shown a distance-time graph with a positive slope, a slope of zero, and then a negative slope. Next, they determined, by trial and error, or by examining the graph, the movement needed for the graph to be automatically created as the sensors collected motion data. For example, to create the distance-time graph mentioned above, they had to move away from the sensor (positive slope), stop (zero slope), and then move back towards the sensor (negative slope).

The practice activity was a success, not only in terms of training students to use the equipment, but also in terms of giving them an understanding of constant motion on a distance-time graph. Norman stated, “There were groups of mine who basically had the whole thing hooked up before I even had it shown on screen what was going to go on. They had everything together and plugged in.” Dianne reported similar levels of student proficiency, attributing this to, “The videos, the [Google Doc] files, and then the fact that we did the run-through.” Dianne reported, “They're getting really nice graphs…I demonstrated with my camera, as I set it up and they watched me walk back and forth, and that's what they did. And they're getting good!” The practice activity clearly helped some students connect motion with the distance-time graph produced by the interface. Norman was also pleased with the asynchronous support Google Doc. He summed up the importance of the practice and feedback for the remote students:

> If you were there in person, it wouldn't have been so bad because you can just make everybody pick up the exact same thing as you, and we'll get together. Or, you can have it all laid out for them. But the virtual [environment] separated everybody, and what equipment they have, and stuff like that. Taking that time [for practice] was a big [advantage]. In my mind, that was a smart move.

Conducting the Inclined Plane Lab

When the synchronous RSII lesson started in Brightspace, over 90% of the students at remote school sites were ready to conduct the lab. They had their equipment set up and were ready for data collection. The students had already learned which materials they needed to procure and how to build an inclined plane from the Google Doc and Screencastify videos. For reasons that will be discussed later, a group in one school had difficulties. With that group, several students joined online from home, and did not have physical access to the equipment and inclined plane apparatus.

Lesson Progressions in Remote Science Inquiry Instruction

The introduction to the RSII lesson that Dianne and Norman used started with a modified check-in. This check-in asked the students to indicate whether they were ready for the experiment by selecting checkmarks on their Brightspace screen. Students were asked to collect images of their apparatus and the process they followed in setting up the equipment as evidence that they had the skills. Norman reminded students of the most important step, "Plug in the power last!" In less than 5 minutes, the students verified the ready status of their equipment, their sensors started making clicking noises, and the students were ready to proceed.

The formal lab started with a short review of the types of constant motion. This was an important reminder for the students. The short review reinforced the practice activity and set up the students to begin the formal "Motion on an Inclined Plane" lab. Before the class, the students received a lab document shared on Google Docs. Both teachers referred to this document as they reviewed uniform motion, acceleration, average velocity, and instantaneous velocity. However, this is where their lessons differed slightly. Dianne did not review acceleration on distance-time graphs, thereby making the lab a structured inquiry. In contrast, Norman reviewed the lab's expected results as part of a confirmation inquiry (Banchi & Bell, 2008). The review lasted approximately 5 minutes and led into the first formal part of the "Motion on an Inclined Plane" lab, which was making a prediction. This formally started the POE portion of RSII.

The teachers asked the students to represent the rolly object (Figure 2) as it moved down the inclined plane. Each teacher drew a sample prediction (Figure 3) and encouraged students to draw their own prediction on their lab report sheet.

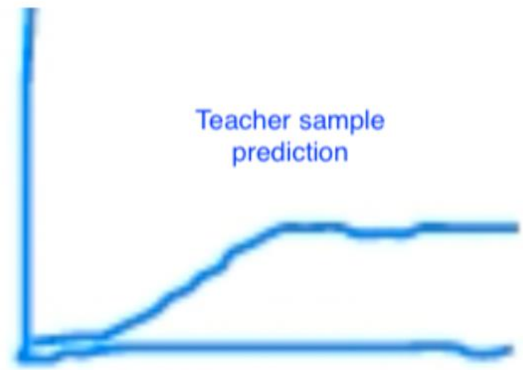

Figure 3. A Sample of Norman's Prediction (RSII Lesson Field Notes)

In asking for a prediction, the teachers were getting the students to represent observed motion as a graphed shape. How the students responded revealed their kinematic reasoning and all the students drew their prediction on the designated section of their lab report. The teachers encouraged students who wanted to share their predictions to draw on the Brightspace whiteboard. Dianne encouraged the students saying, "Your prediction is not going to be wrong, because it's what you think!" She added, "Is our experiment going to support what we thought it would look like? That's the fun part!"

Interestingly, nine out of ten of the public predictions were incorrect (Figure 4); as were many of the predictions observed on the student lab reports. In Figure 4, Students 5 and 4 demonstrated a common misconception, which is that the graph will take the same shape as the observed movement of an object down an inclined plane. Student 7 had the closest prediction but did not account for the change in velocity as an object accelerates down a ramp. Figure 5, in which the line curved from 0.6 s to 1.6 s, indicates this change in velocity. It was important for the teachers to know about student misconceptions so that they could guide data collection and offer appropriate instruction as the lab continued.

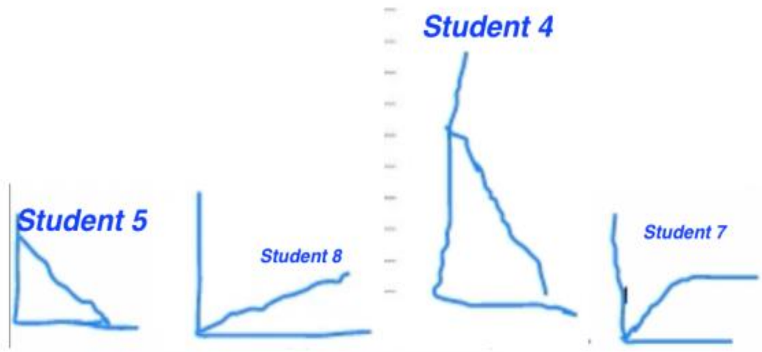

Figure 4. Student Predictions of Distance-Time Graph for Object Rolling Down an Inclined Plane.

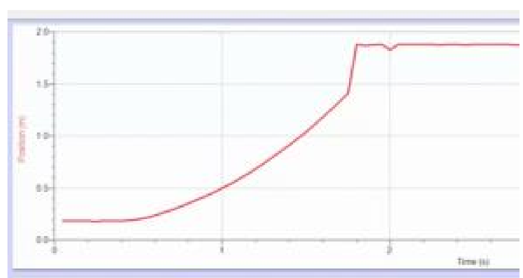

Figure 5. The graphical result of rolling an object down an inclined plane.
Note. Figure 4 and Figure 5 show distance on the y-axis and time on the x-axis. Figure 5 shows the curved line that is typical of acceleration.

Norman conducted the confirmation inquiry. During the LS Reflect phase, when Norman was asked if his students understood motion on an inclined plane, he said, “Well, the fact that none of them got predictions right really became something else. But none of them got predictions right.” Many students in all classes demonstrated well documented challenges in expressing the motion they observed as a graphical prediction (Beichner, 1994; Kozhevnikov & Thornton, 2006).

Data Collection and Students at Home

At approximately 15-minutes into the lab, the students in each RSII class started data collection. Norman had set up lab groups in which each student had a role. This ensured that COVID-19 protocols were followed for high-touch surfaces and objects such as the rolly object. Both teachers were active as students quickly shared their results on Brightspace. When a student asked about the sharp change in the graph followed by a slope of zero (Figure 5), Norman explained that "The first two seconds of the experiment was a nice graph." After that, there was a "crash at the end," resulting in a zero velocity. Throughout data collection, the teachers offered similar dynamic formative assessments. They also provided scaffolding for students to understand the results, such as reminding them to identify errors and to clarify which parts of the graph provided good data. This was done for each unique data set from multiple DE school sites.

Students Who Missed the Activity

Several students were unable to attend school during the lesson and were accommodated in two ways. If the student could connect to Brightspace for the synchronous class, they guided the teacher through the experiment, sending the teacher text messages on what to do next. If the student could not connect to Brightspace, they watched a recording of the other students guiding the teacher through the experiment. Whether the student did the lesson at home using Brightspace or watched a recording, they used the same Google Drive data files as the other students.

All of this happened at the same time as students at DE schools who did not need accommodations conducted their experiments. Students at home with access to Brightspace guided the teachers through data collection. Acting as proxies for the students at home, Norman and Dianne watched the Chat on the video feed. They followed the instructions students typed into Chat as they completed the rolly object experiment. When students at home typed, “Go!”, the object was set in motion on the inclined plane and the graphical results were presented in the application that was being shared in Brightspace. This process involved several characteristics common in a remote lab (de Jong et al., 2021).

The Unsuccessful Group and Teacher Noticing

CDLI computers do not have a camera because of bandwidth issues. Due to this sensory limitation, it can be challenging for teachers to notice classroom events (Criswell et al., 2021). Most data sharing between the students and teachers was ongoing. The teachers communicated with their students about the shapes of their graphs. The lack of results from one school group stood out to Norman, “I found that the school that had the most difficulty keeping on track and getting good results was the school that had other [non-science] students in the room with them at the same time.” Norman offered a solution. He suggested that teachers tell their students to turn on their Chromebook and camera. That way, the teachers could watch what was happening in class. Norman also said this about the noticing issue:

> The challenges and needs that became apparent were that students often could use more direct guidance than was easily possible at times . . . While they could see me, I could not see them, and was relying on their description input to help me troubleshoot and explain things. I feel if I was able to see them, these issues would have been much more readily addressed.

With improved remote internet reliability, the student cameras could be turned on. That would better support teacher noticing on Brightspace, and thereby allow teachers to manage and support student activities more effectively.

Images and Student Skills

Additional Screencastify videos trained students in how to scale graphed data so that they could better resolve slopes. During the lab activity, teachers did not have time to review how graphs can be rescaled. Their primary concern was to ensure that students had an appropriate curve for examining instantaneous velocity and to complete their lab report. As they worked through the lab activity, some students demonstrated that they had learned how to rescale graphs from watching the Screencastify videos. Norman said to the other teacher, “I was wondering if you modified [the students’ graphs] for them, then sent it back to them to work on?” Dianne replied, “Yeah, and some of them modified [their graph] themselves.” Further, when Norman said that some of his students made “a better curve,” he meant that they adjusted their graph scales to better demonstrate the relationship between the variables. In other words, they adjusted the x or y axis to show the relationship of distance more clearly over time. That the students were able to do this suggests that they learned how by following the instructions given in the Screencastify videos.

Predict–Observe–Explain Inquiry and Data Collection

By the end of the synchronous RSII session, all the student groups except for one, as well as all of the students learning at home, had successfully collected inclined plane data and had completed the Observe stage of the POE strategy of inquiry. The students included an analysis of their results in their lab report, thereby making it possible for them to also address their predictions and any misconceptions they may have had. The students' goal in completing the report was to use their lab data to calculate tangent slopes and demonstrate the instantaneous changes in velocity that occurred during the experiment. As part of the Explain stage of POE inquiry, students were asked to address any misconceptions they had about motion. Unfortunately, we could not access student-written reports and relied on second-hand reports from the teachers (below).

Predict-Observe-Explain Inquiry and Student Engagement

During the reflect phase of LS, POE predictions and formative evaluations were discussed. All teachers agreed that the student predictions were more than just a tactic to promote cognitive engagement. Norman observed that student predictions were also a good way to keep students motivated. "A lot of times with your high-school students, there's a certain complacency and getting them to start off by making the prediction gets them in the mind to start thinking about what they're doing. Right?" Although many of the predictions were incorrect, there was nevertheless value in getting the students to make a prediction. As Norman said, "They realize that afterwards. But they were just making their predictions." Dianne reported that students started to connect the graphical motion and data sets with observed motion. "I like how the velocity sets them up and the kids now know how to verify if it's actually stopped. They'll go down [in the data], and check and see if the velocity is zero." For Dianne, instructing classes using data collected by students and the graphs served a cognitive purpose:

> It's the first time I've done graphs, yeah, especially the distance-time graphs they're able to describe . . . I'm like, 'Write me three lines that describe the object moving.' And they're like, 'It stopped for a few seconds. It moved forward at a fast velocity. Stopped. It paused, and it

> came back toward where it started.' And they're actually starting to put paragraphs together for me.

Dianne also thought that building the apparatus and having the physical experience of conducting the lab was important for student learning and engagement:

> It's ownership. It's authenticity. If it's not yours, you're not going to remember. It is not going to mean anything . . . So, once the kids get that in their hands and that becomes their experience, that was their ball, that was their ramp, that was their graph. We talked this morning about how we analyzed the graph of the big blue ball. That big blue ball meant something to those kids. That graph all of a sudden became theirs . . . and that's what enriches the activity. So, the more you can get the kids engaged and it becomes theirs, then that's where you're learning and your deeper learning starts.

The focus group had many comments that echoed Dianne's sentiment. The focus group also reaffirmed the value of placing students, not teachers, at the heart of the lesson. This approach has been well-proven by research.

Discussion

Kennepohl (2103) summarized the forms of DE science lab used for home study, virtual learning, and remote locations. Home study was described as a higher-education strategy for learners that allowed them to conduct labs off-campus. In order to complete home study, students used lab kits, practical kitchen science, household items, and self-directed fieldwork. RSII is a newly reported form of DE instruction that blends synchronous and asynchronous teaching. With RSII, skills are taught using physical and virtual resources. As part of the lab, students practise doing the skills they have learned, either on their own or with a DE teacher. Kennepohl suggests that simulations offer students autonomy, feedback, and the ability to explore phenomenon in an engaging manner that allows the students to control variables. “One can speed up or slow down different components of the work, which provides time to explore and relieves a student of tedious work not directly related to learning” (Kennepohl, 2103, p. 676). Similarly, the students of this study learned how to use the version of the interface on their system by exploring the Google Doc and repeatedly watching Screencastify videos. This allowed them to prepare for synchronous RSII.

How does a remote inquiry compare to an inquiry that uses RSII? Remote laboratories “employ remote control when an experiment or instrument is physically inaccessible.” By doing that, remote laboratories offer access to expensive equipment (Kennepohl, 2013), such as engineering apparatus (de Jong et al., 2013) or real equipment accessible at distance for science, technology, engineering, and math (STEM) education (de Jong et al., 2014). The results of remote inquiry are real and require students to analyze their results. Students will receive support as they do remote inquiry. However, that support may not come from a teacher who can answer questions that pass the *Turing Test* and deal with complicated graphs, by saying things such as, “If you ignore the peaks, it is a pretty good graph!” (Dianne). The Turing Test was conceived by Alan M. Turing as a way of determining whether a computer can think (Britannica, September 19, 2022). In this context, we are using the term to emphasize that teachers offer extra support to students specifically because of their ability to think and react.

Sinatra et al. (2015) noted that misconceptions are both prevalent and persistent in science possibly due to the “experiential nature of our background knowledge with science concepts”, adding that “many science conceptions conflict with human experience and perception” (p. 5). Given that students may have little experience with motion on an inclined plane and acceleration, it is not surprising that most of their predictions were incorrect or incomplete. Kozhevnikov and Thornton (2006) suggested that technology helps students understand motion concepts by linking graphical representations that show an object undergoing different types of motion. Graphs that show real and predicted motion of an object over time help students cognitively link motion with how a graph looks. The path to conceptual change (Posner et al., 1982) is seeing an object in motion and simultaneously watching graphs being created that represent the motion, even when this is presented as a demonstration (Hynd et al., 1994) or a simulation (Price et al., 2019) that students watch. The pre-lab practice with its multiple repetitions of experiments helped students make the connection between an object in motion and a graphical representation of that motion. This helped students understand constant motion. Without similar practice with acceleration, it is not surprising that inexperienced students struggled with this new type of motion.

Beichner (1994) found that students may have difficulty understanding graphs and noted that "graphs are efficient packages of data," which makes them an important part of the vocabulary of physics learning (p. 751). Students may experience difficulties with graphical relationships, such as connecting acceleration with the fundamental change in shape shown on a distance-time graph as shown in this study (McDermott et al., 1987). Kozhevnikov and Thornton (2006) reported that different physics topics and problems have different spatial-visualization requirements. For example, "finding solutions for one-dimensional problems involving judgments about motion characteristics of only one object" (p. 165) may make lower demands on the visual-spatial working memory than multi-dimensional problems such as an acceleration graph. This seems logical. Acceleration interpreted as a rate of change versus constant motion is shown as a slope on a graph, and this derivative relationship may be a challenge for some students to understand (Jones, 2017). Kozhevnikov and Thornton (2006) referenced cognitive research to explain that interpretations of kinematic graph problems, such as the predictions by the students in this study, “require high visual-spatial resources" (p. 125). They go on to suggest that translating “an abstract graphical representation into a real motion event” is a process in which so-called “low spatial students” might experience more difficulties (p. 125). Kozhevnikov and Thornton (2006) go on to suggest that memory-based learning (MBL) reduces cognitive load. We agree that graphical representations such as RSII for motion on an inclined plane are useful for solving this problem. At the very least, using POE opens a window into student misconceptions and sets the stage for using student-collected data and teacher scaffolding, to start the process of conceptual change (Posner et al., 1982).

The teachers of this study believe student ownership is possible in a remote classroom. Enghag and Niedderer (2008) found that students in lab groups for physics mini-projects demonstrated individual ownership through their actions of choice and control. A study of science student ownership by O’Neill (2010) examined physical structures and found that the teacher’s role is integral in “aiding [the] student’s cultivation of ownership” (p. 17). In RSII, having the students working on their own to use data collection tools was vital to the experiment. The students demonstrated engagement and ownership, which can result in “increased levels of science engagement, and promote authentic participation” (p. 19). Szalay and Tóth (2016) studied step-by-step inquiry in chemistry with students similar in age to the students in this investigation. They found that step-by-step inquiry developed skills required for experimental design and they suggested that "It is worth modifying traditional practical laboratory activities to ones where experiments have to be partially designed by students" (p. 929).

Blending Virtual and Physical in Remote Science Inquiry Instruction

In two reviews, Brinson (2015, 2017) examined learning achievement during traditional labs with hands-on activities versus non-traditional labs that are either virtual or remote. Brinson found that the virtual and remote labs were as good as or better than traditional labs in many categories of learning. RSII labs have aspects of both traditional and non-traditional labs. The non-traditional labs in RSII blend Screencastify videos with hands-on use of a virtual or physical apparatus. As set out in the science and engineering practices included in the Next Generation Science Standards, students in this study had to plan and carry out investigations, analyze and interpret data, use mathematics and computational thinking, and construct explanations (NRC, 2012). This covers four of the eight science and engineering practices. In "Light and Colour," a study that employed both physical and virtual manipulatives for teaching the topic, Olympiou and Zacharia (2012) found that the blended condition "enhanced students' understanding of concepts that were introduced through the curriculum material of the study" (p. 38). They found that the students' understanding was enhanced more by the blended condition than it would have been by singular physical and virtual conditions. We agree with their suggestion that the RSII blending of materials is "more conducive to learning through laboratory experimentation" (p. 42).

Conclusions and Limitations

The structure of LS fits well with the basic premise of good inquiry for professional learning. According to this premise, good inquiry should be situated in the teacher's context (Lave &

Wenger, 1991), include reflection (Schön, 1983), and involve a proven model for inquiry instruction (White & Gunstone, 1992). In some ways, RSII is similar to a home-study lab (Kennepohl, 2013), simulations (Price et al., 2019), and remote labs (de Jong et al., 2014). However, these distinctive types of remote instruction lack the unique blended asynchronous and synchronous forms of instruction found in RSII. Further, this investigation demonstrates that students can successfully conduct an inquiry when provided asynchronous resources and online synchronous support. This investigation reinforces the importance of predictions in science instruction as an essential part of finding misconceptions and addressing them as the students construct meaning during the inquiry process (Colburn, 2000).

We recognize that qualitative inquiry is subjective. This study contains inferences about student engagement, ownership, and learning that are not quantitative. We could not review student labs. This limited our ability to find and more accurately describe student misconceptions.

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Chapter 4 - Mediation and Expansive Learning During Remote Lesson Study: An Activity Theory Analysis

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Abstract

This qualitative case study uses Cultural Historical Activity Theory (CHAT, Engeström, 1987) to examine distance education high school science teachers' activities, actions, and operations during a remote lesson study (LS). The *subject* of this CHAT analysis was a three-teacher LS group (the first author was a teacher). The *object* of the subject activity was the science inquiry lesson developed during two cycles of remote LS. In CHAT, the subject and object are two of the three nodes of a triangle, and the third node is mediating signs or *tools*; collectively, the nodes form a first-generation activity system (Vygotsky, 1978). However, this CHAT analysis involves a second-generation activity system (Engeström, 1987) that includes three nodes under the first-generation system; a *community* node (includes the remote school students, supporting staff, and district distance education staff), a *rules* node (for school sites, class expectations), and a *division of labour* node (for LS tasks and tool development). The actions and operations of the subject in the second-generation activity system varied temporally from the professional development for LS and scientific inquiry to and through the LS phases: *study*, *plan*, *teach*, and *reflect* (Lewis et al., 2006). During the study and plan phases, the LS group negotiations and operations, such as deciding on probes to use and testing the equipment, shaped the lesson idea or object germ cell to develop and teach a remote science inquiry. The LS group's object-motivated activity facilitated the lesson development from the initial germ cell idea to the complete inquiry lesson of motion on an inclined plane. However, the lesson

ontogeny generated level one and two contradictions within the activity system. For example, the perceived need to support remote students' independent use of data collection devices resulted in actions and operations to produce tools. These mediating tools, such as Google Docs with hypermedia, asynchronously trained the students to successfully use the instruments to conduct an independent inquiry at the remote sites during the teach phase of LS. The acceleration inquiry document, another tool developed by the subject, required student predictions that were signs or psychological tools for both the teachers and students when the predictions conflicted with the graphical outcomes of the data collection – producing level-one contradictions within the subject during the teach and reflect phases. Addressing this and other contradictions set the conditions for expansive learning by the subject described in this chapter.

Introduction

Engeström (2015) reported that runaway objects, such as the COVID-19 global pandemic, "seem to have a life of their own that threatens our security and safety in many ways. Runaway objects are contested objects that generate opposition and controversy." (p. xxxvi). From 2020 onwards, the world medical community struggled to mitigate the health impacts of a novel coronavirus (SARS-CoV-2) that emerged in China (Sohrabi et al., 2022). In education, the COVID-19 runaway object necessitated an unprecedented move to complete online instruction for preservice and in-service teachers (Hartshorne et al., 2021). Recent innovations in communications technology such as Zoom, Skype, and Google Meet, were used experimentally pre-pandemic to conduct professional learning (ex. Moore, 2018) and as digital tools (Weaver et al., 2021) to successfully conduct remote lesson study (LS). The many LS professional learning adaptations to the pandemic lockdowns are examples of resilience and innovation in the face of the shifting threats of COVID-19 (Calleja & Camilleri, 2021; Huang et al., 2023). This research, part of my doctoral thesis, was contested by unpredictable pandemic dynamics, requiring levels of reflexivity, such as rewriting research protocols, not previously reported in teacher research projects conducted in the same context (Goodnough, 2018; Goodnough et al., 2019). The teachers conducted a remote inquiry (Wells et al., 2022) for distance education science instruction in the face of shifting pandemic requirements.

This study uses Cultural Historical Activity Theory or CHAT (Engeström, 1987) to frame the online LS teacher research that focused on a remote student science inquiry directed by e-teachers with distance education students (Wells et al., 2022). Kaptelinin (2005) suggested that from a research perspective, analysis of the object of activity supports understanding of "the 'ultimate reason' behind various behaviours of individuals, groups or organizations" (p. 5). Several alternate constructivist learning theoretical perspectives were considered for this study, such as Bruner's examination of learners as agents impelled by self-generated intentions or the teachers' operations within a community of practice (Lave & Wenger, 1991; Wenger, 1999). However, the limited student data and the intense focus on three teacher participants (the LS group) proved these models unsuitable for framing a research lesson developed during a remote LS (Wells et al., 2022).

The lesson used digital tools (Weaver et al., 2021), such as motion sensors and data collection interfaces with students in multiple geographically disparate distance education sites. While a community was involved with this lesson, the study was not community focused as the LS teachers' lesson development was a collaborative effort that was "broader than individual action… practical, object orientated work" (Engeström, 1999, p. 12). Meaning within the context of a runaway object, the motivated LS group developed a remote science lesson over 16 weeks that, when presented, produced community feedback that contributed to teachers' expansive learning (Engeström, 1999). Expansive learning and activity theory (Engeström, 1999, 1987) are subsequently be reviewed; however, since the LS was the context of the analysis, this literature examination starts with the LS (Lewis et al., 2006a).

Literature Review

Lesson Study Teacher Research

Lesson study has been practiced in Japan for over 100 years (Seleznyov, 2018). Traditionally, a form of math teacher professional learning (Stigler & Hiebert, 2009; 2016), it is increasingly popular with science teachers (Chong & Kong, 2012; Dotger & Walsh, 2014; Kolenda, 2007; Lee Bae et al., 2016; Maguire et al., 2010; Ogegbo & Gaigher, 2019; Perry & Lewis, 2009). LS is touted as effective professional learning (Saito et al., 2012; Cheung & Wong, 2014; Lee Bae et al., 2016; Vermunt et al., 2014; Willems & Van den Bossche, 2019), and science teachers reportedly value the reduced isolation (Kolenda, 2007), collaborative planning for one lesson (Allen et al., 2004; Jansen et al., 2021), and research aspects of LS (Maguire et al., 2010; Ogegbo & Gaigher, 2019).

The LS learning cycle (Figure 1) is similar to action research, where teacher researchers collect, analyze, and reflect on data (Dana & Yendol-Hoppey, 2019; Kemmis, 2009).

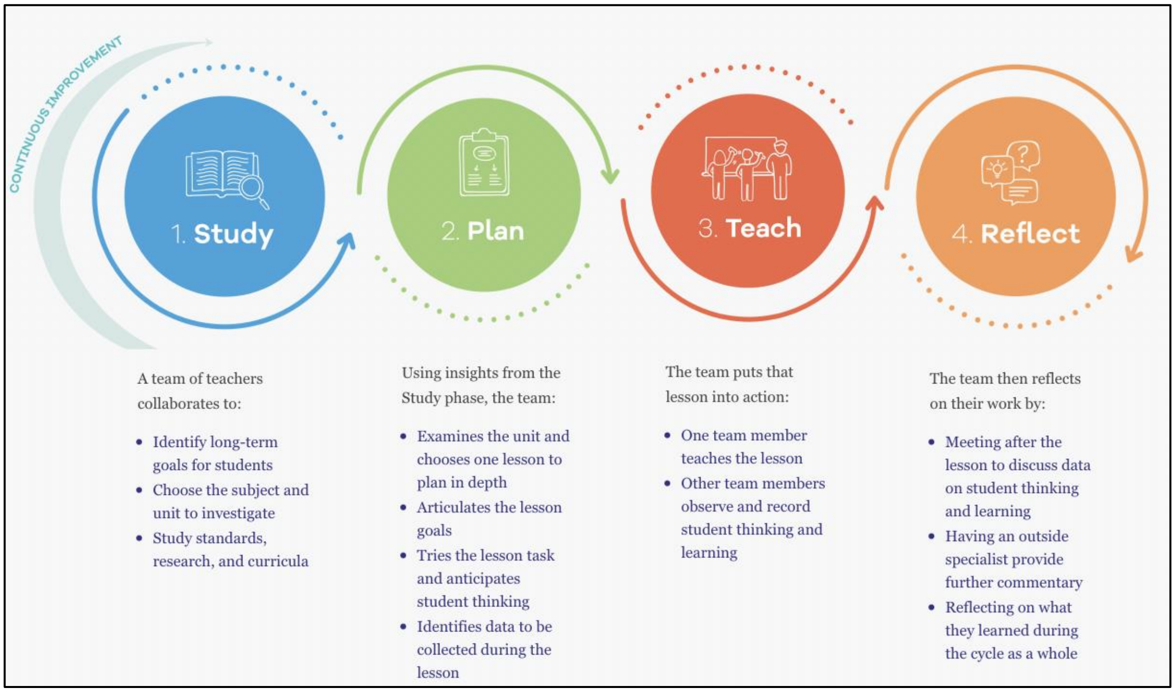


Figure 1 - The lesson study cycle (The Lesson Study Group, Mills College, https://lessonresearch.net/about-lesson-study/what-is-lesson-study-2/)

However, the research questions of action research may have many roots in practice (Dana & Yendol-Hoppey, 2019), while the LS research focus is rooted in the curriculum of a select unit (Lewis & Hurd, 2011), where preparing a chosen research lesson has a student focus, particularly student thinking and learning challenges related to the task (Lewis et al., 2006; Lewis & Takahashi, 2013). This strategy guides the teachers to concentrate on students during the creation of the lesson (Akiba et al., 2019; Dudley, 2013; Lewis & Hurd, 2011). An interesting LS practice not used in this study is choosing students to interview to provide additional data for the lesson reflection (Dudley, 2014). Despite this difference, the LS focuses on the students and student thinking during the research lesson within a collaborative and negotiated environment, fostering instructional improvement (Hiebert & Morris, 2012; Lewis et al., 2006b; Lewis et al., 2012).

Remote/Online Lesson Study

According to a review by Huang et al. (2021a), Budak published investigations of online LS as early as 2012. Thirteen remote LS publications were identified by Huang et al. (2021a), with six similar to the present study, reporting fully online LS. All the studies, even hybrid LS, reported varying degrees of success while using digital technologies such as Google Docs and Google Drive, which were "very convenient and powerful document storing and sharing, and participants can work on the same file simultaneously" (Huang et al., 2021a, p. 108). Weaver et al. (2021) reported that digital tools supported LS teacher candidate learning and fostered discussions and debriefing; however, due to technological and instructional issues, these authors also reported that "digital tools limit instruction" (p. 193).

During and post-pandemic, LS in virtual/hybrid environments increased in terms of cross-cultural LS (Huang et al., 2023), where innovation and collaboration produced stable and effective remote teacher professional development. The teachers of this study developed their PCK for online inquiry during remote LS (Wells et al., 2023), while Huang et al. (2021b) analyzed the contradictions of math teachers of an international LS group to report expansive learning (Engeström, 1999). To place the results of Huang et al. (2021b) and other activity theory examinations yet to be presented in context, first requires a review of Engeström's activity theory (1987). Further, expansive learning (Engeström, 1999), the types of contradictions, and how these arise and may influence LS learning are subsequently reviewed.

Cultural-Historical Activity Theory

CHAT is multidisciplinary, with applications beyond psychology to, for example, medicine, industry, and education (Engeström, 1987). However, the genesis of this theory can be found in the studies and writing of Vygotsky, Leont've, Luria, and others who were, over nine decades ago, prominent contributors to Soviet developmental psychology (Wertsch, 1981). These authors were strongly influenced by the materialism and human activity of Karl Marx and Engel's activity and dialectics: "These two philosophers insisted upon the need to include human activity as a fundamental building block of their theoretical framework "(Wertsch, 1981, p. 9). Wertsch pointed to the inspiration of Marx and Engel, resulting from how they "emphasize that only by interacting with the material world and with other humans can we develop a knowledge of reality" (p.11).

Mediation of Human Activity

Vygotsky and his colleagues did not support the reductionist research from the West that atomized behaviour into stimulus and response, and he suggested the concept of mediation with tools or signs (Vygotsky, 1978). While Vygotsky largely accepted the behaviourist work of Pavlov, his studies of human language and the use of signs "touched on semiotic questions not raised by Pavlov" (Wertsch, 1985, p. 91). For example, a typical response to a stimulus, S to R, will become classically conditioned over time (Figure 2). In a mediated response of S to R, X can be an external artifact that acts as an auxiliary stimulus, "When a human being ties a knot in her handkerchief as a reminder, she is, in essence, constructing the process of memorizing by forcing an external object to remind her of something; she transforms remembering into an external activity." (Vygotsky, 1978, p. 51). Wherever there are humans, with language and signs as cultural tools, there are cultural practices and learning (Vygotsky, 1978); even as we function and learn in the workplace (Engstrom et al., 1999). Activity theory (Engeström, 1987) is a mechanism to examine work and learning; one of the basic tenets is the concept of mediation.

Meaning Vygotsky and Leont've made significant contributions, to this study and the First-Generation Activity System (Engeström, 1987), in examining how the activity of a Subject toward an Object is mediated by artifacts (Figure 2).

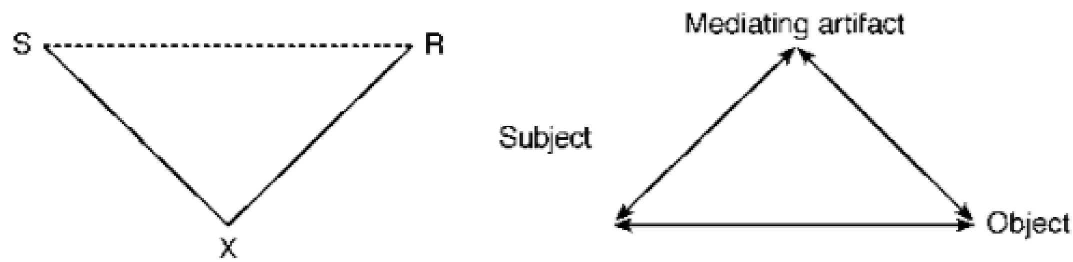


Figure 2. Left: Vygotsky's mediated response to (R) a stimulus (S). Right: A First-Generation Activity System where tools and other artifacts mediate the Subject's activity toward the Object (Engeström, 1987).

While John Dewey (1938) did not openly identify mediation in teaching, he was, however, aware of this human condition in education:

> Foresight of consequences involves the operation of intelligence. It demands, in the first place, observation of objective conditions and circumstances. For impulse and desire produce consequences not by themselves alone, but through their interaction or cooperation with surrounding conditions. (p. 67-68)

Engeström (2001) believed mediation via cultural artifacts and language was necessary for the examination of human activity, actions, and motives:

> The insertion of cultural artifacts into human actions was revolutionary in that the basic unit of analysis now overcame the split between the Cartesian individual and the untouchable societal structure. The individual could no longer be understood without his or her culture means; and the society could no longer be understood without the agency of individuals who use and produce artifacts. (p. 134).

The LS group produced tools for the research lesson as forms of mediation over distance; however, all tools are not of the same ilk.

The Types of Mediating Tools

Wartofsky (1979), in discussing perception in a historical and evolutionary context, categorized two forms of tools or artifacts and their place in "human historical praxis" (p. 200). Human survival is linked to the creation of artifacts and these tools; their use and learning to use them "creates such skills as themselves artifacts, even where these skills do not entail the use of tools in the ordinary sense" (p. 201). Wartofsky suggests a primary tool is an "axe, club, needles, ball, etc.". In contrast, "artifacts created for the purpose of preserving and transmitting skills, in the production of primary artifacts" are considered secondary artifacts (p. 201). The modes of secondary artifacts may be gestural, oral, and visual, "such that they may be communicated in one or more sense-modalities; such, in short, that they may be perceived" (p. 201). The secondary artifact connection to historical praxis is through the transmission of a preserved mode of action where "The mimetic character of such representations consists not simply of their imitation of natural objects or animals, but in their imitation and representation of modes of action, or praxis" (p. 202).

To Vygotsky, there are also two forms of artifacts or tools: physical (technical) and psychological (Wertsch, 1985). "Vygotsky extended Engel's notion of instrumental mediation by applying it to 'psychological tools' as well as to the 'technical tools' of production" (p. 77). Vygotsky refines his vision of the different types of tools:

> The invention and use of signs as auxiliary means of solving a given psychological problem (to remember, compare something, report, choose, and so on), is analogous to the invention and the use of tools in one psychological respect. The sign acts as the instrument of psychological activity in a manner analogous to the role of a tool in labor" (1978, p. 52)

Thus, signs are psychological tools while instruments are required for labour or production (Wertsch, 1985).

Activity: The Connection Between the Subject and Object

Activity theory is a theory of object-driven activity, and through their activities, people constantly change and create new objects (Engeström, 2009). When considering activity systems, the first-generation system focuses on the subject and mediated action that is object focused. According to Engeström (2009), "Objects are concerns; they are generators and foci of attention, motivation, effort, and meaning" (p. 304). The motive was a seminal activity driver for Leont've as he was aware of the goal-directedness of activity (Wertsch, 1981). Leont've (1978) states that "a constituting characteristic of activity is its objectivity" (p. 52). He particularizes the object-activity relationship below:

> The expression "objectless activity" is devoid of any meaning. Activity may seem objectless, but scientific investigation of activity necessarily requires discovering its object. Thus, the object of activity is twofold: first, in its independent existence as subordinating itself and transforming the activity of the subject; second as an image of the object, as a product of its property of psychological reflection that is realized as activity of the subject and cannot exist otherwise.

Leont've (1978) described a loop-like circular structure process for all activity starting with "initial afferentation → effector processes regulating contacts with the object environment → correction and enrichment by means of reverse connections of the original afferent image" (p. 53). He then elaborates that the afferent agent directing activity "is primarily the object itself, and only secondarily its image as a subjective product of activity that fixes, stabilizes, and assimilates its object content." (p. 53). From an activity research perspective, object activity is the "sense maker" (Kaptelinin, 2005, p. 5).

The Object Germ Cell

Before the image of the object is fixed, it must be sparked into existence. This may be a moment or a process that produces what Engeström calls the germ cell (2015).

> A new theoretical idea or concept is initially produced in the form of an abstract, simple explanatory relationship, a "germ cell." This initial abstraction is step-by-step enriched and transformed into a concrete system of multiple, constantly developing manifestations. In learning activity, the initial simple idea is transformed into a complex object, into a new form of practice. (p. 26)

Conducting a remote inquiry lesson (Wells et al., 2022) was first an idea that was transformed from the germ cell into an image of the object through the LS process. This process is essential for the ontogeny of the objective, an important component of the subsequent analysis in this paper. However, there are levels within the examination that must be considered.

Leont've and The Levels of Analysis

A subject's inner afferent vision or "image" of the object regulates activity in a reverse feedback loop within the object environment, where object "correction and enrichment [occurs] by means of reverse connections of the original afferent image" (p. 53). Leont've suggested activity has three levels of analysis (Figure 3), summarized by Wertsch (1981), "activities are distinguished on the basis of their motive and the object to which they are orientated; actions, on the basis of their goals; and operations, on the basis of the conditions under which they are carried out (p. 18). An example of the cascade of the levels of analysis used by Leont've is human activity motivated by food where, "in order to satisfy his/her need for food, he/she [they] must carry out actions that are not immediately directed towards obtaining food" (Leont've 1981, p. 60). For the activity of fishing, building a fish spear is an example of a goal-directed action with operations such as cutting the spear pole with a saw and fashioning the spearhead, where “he/she [they] must carry out certain operations and must know how to perform them” (Leont’ve, 1981, p. 65).

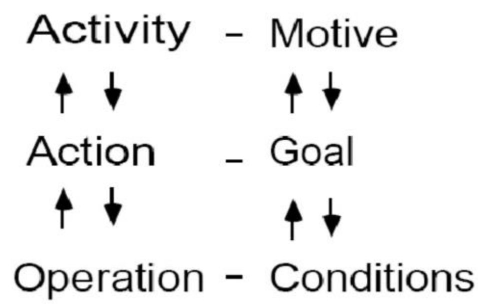


Figure 3. The three levels of analysis within activity (Leont’ve, 1981)

The above example of activity, fishing, demonstrates how the various grain size or levels of analysis of Leont’ve (1981) can support the study of the object or “sense maker” towards understanding “the ‘ultimate reason’ behind various behaviours of individuals groups or organizations” (Kaptelinin, 2005, p. 5). With groups, the analysis of “Tool mediation not only captures the relationship between subject and object but is also closely associated with other activity moments such as community and division of labor” (Roth et al., 2009, p. 145). Expanding analysis beyond the first-generation activity system to include community and division of labor requires the second-generation activity system of Engeström (1987).

The Second-Generation Activity System

Engeström (1987) used the theories of Vygotsky, Luria, and Leont’ve when he developed the second generation of CHAT (Figure 4). The *Subjects* still conduct activity towards the *Object* with mediating artifacts; however, a second-generation system situates the subject socially (Engeström, 1987). “The concept of activity took the paradigm a huge step forward in that it turned the focus on complex interrelations between the individual subject and his or her community” (Engeström, 2001, p. 135). This is generally opposed to variable isolating quantitative research as:

> Viewing the world of a person’s ideas, beliefs, and (intellectual) knowledge as autonomous-essentially disconnected from their body (i.e. lived) experience, and hence, from their social cultural context- provides broadly for a devaluing of lived experience in favour of higher (abstracted) contemplative activity. (Kirshner & Whitson, 1997, p. 4)

Engeström (2001) identified five principles to help summarize activity theory. The first principle that features prominently in this study is mediation. The second principle is multi-voicedness, as “an activity system is always a community of multiple points of view, traditions and interests” (Engeström, 2001, p. 136) that created the different positions of participants (such as the students and teachers). The third principle, historicity, accounts for the activity systems “take shape and get transformed over lengthy periods of time” (p. 136). For example, the Centre for Distance Learning and Innovation (CDLI) has been dedicated to remote teaching in Newfoundland and Labrador for over 20 years (https://www.cdli.ca). During that time, there have been changes to instruction – such as the addition of D2L and modifications created by the evolution from Web 1.0 (Murphy & Rodriguez-Manzanares, 2008) to Web 2.0, Brightspace and beyond (Wells et al., 2022). Contradictions are “historically accumulating structural tensions within and between activity systems” (Engeström, 2001, p. 137), contributing to the fourth principle of activity theory, the seminal role of contradictions in change and development. In this study, the second-generation activity system, Engeström’s fifth principle is the “collective, artifact-mediated and object-oriented activity system, seen in its network relations to other activity systems, is taken as the prime unit of analysis.” (Figure 4, Engeström, 2001, p. 136).

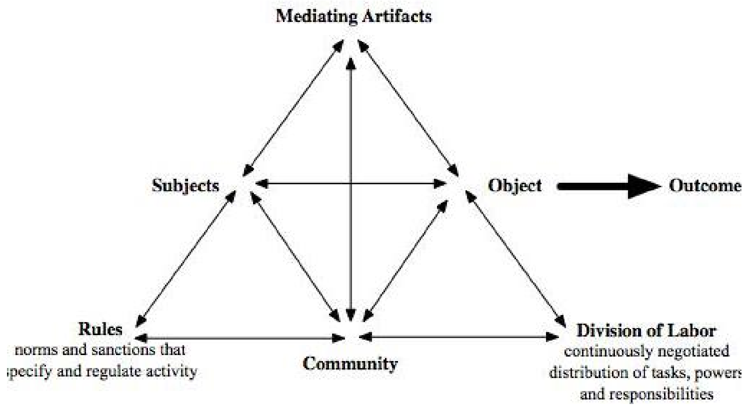


Figure 4. A Second-Generation Activity System (Engeström, 1987)

Second-generation Activity System Nodes

The lower portion of the triangle shows an additional three nodes that connect with the Subjects, Mediating Artefacts, and the Object (Engeström, 1987, Figure 4). The community is the cultural group to which the subjects belong – such as teachers who are members of a school community that may include students, administration, staff, and district personnel. The community and subject's activity, actions and operations are regulated by norms and regulations such as structured class times, in-class social expectations, and the adherence to curriculum outcomes during instruction. The division of labor is the continuously negotiated distribution of tasks (horizontal) and power (vertical) (Engeström, 2001). Horizontal task distribution could be the negotiated assignment of tasks by LS teachers in developing a lesson, and vertical or power distribution could be the rotation of the LS group leader for LS meetings (Lewis & Hurd, 2011). The principle of multi-voicedness is found in and between nodes of the second-generation systems as "an activity system is always a community of multiple points of view, traditions and interests" (Engeström, 2001, p. 136) and, within the present study, the "collective, artifact-mediated and object-oriented activity system, seen in its network relations to other activity systems, is taken as the prime unit of analysis." (p. 136).

Engeström's third principle, historicity, accounts for the activity systems "take shape and get transformed over lengthy periods of time" (2001, p. 136). For example, the Centre for Distance Learning and Innovation (CDLI) has been dedicated to remote teaching in Newfoundland and Labrador for over 20 years (https://www.cdli.ca). During that time, there have been changes to instruction – such as the addition of D2L (https://www.d2l.com) and modifications created by the evolution of Web 1.0 to Web 2.0.

Contradictions within Activity

Contradictions are "historically accumulating structural tensions within and between activity systems" (Engeström, 2001, p. 137), contributing to the fourth principle of activity theory, the seminal role of contradictions in change and development. Using CHAT as a unit of analysis demonstrates that activity in a social system result from contradictions, the driving force of change, with expansive cycles as a possible form of transformation in activity (Engeström, 2001). In *Learning by Expanding*, Engeström (1987/2015) identifies four levels of contradictions within human activity systems (Figure 5):

> Level 1: Primary inner contradiction (double nature) within each constituent component of the central activity.
> Level 2: Secondary contradictions between the constituents of the central activity.
> Level 3: Tertiary contradiction between the object/motive of the dominant form of the central activity and the object/motive of a culturally more advanced form of the central activity.
> Level 4: Quaternary contradictions between the central activity and its neighbor activities. (p. 70)

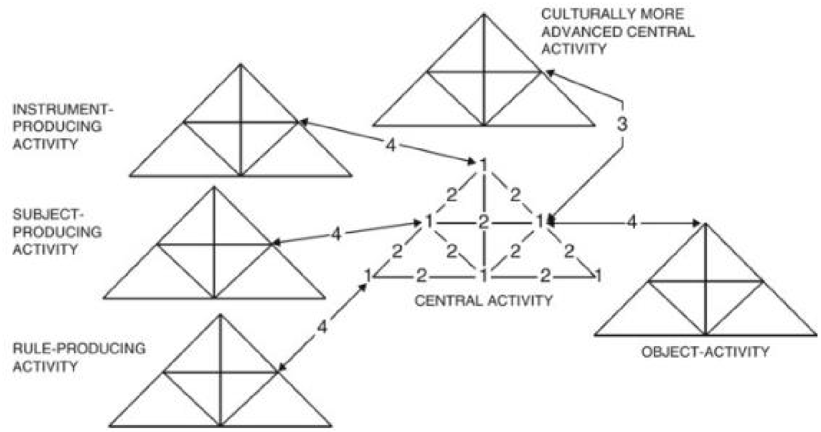


Figure 5. The diagram of contradictions within nodes (1 – primary), between nodes (2-secondary), with central object-motive of activity with more advanced activity (3-tertiary), and between central the neighbouring activity (4-quaternary). Engeström (2015).

A primary contradiction with one node, such as the LS group or the subject node, could be deciding what lesson to select as the research lesson. At the same time, a problem with the distribution of tools, such as lab instruments, from the community to the subject is a secondary contradiction. Dilemmas are manifestations of contradictions (Engeström & Sannino, 2011) and are essential as “contradictions cannot be observed directly; they can only be identified through their manifestations” (p.369). It is challenging to deal with significant contradictions during the developmental process, “Seeing contradiction as an inconsistency or competition between separate forces or priorities corresponds to the general mechanistic tendency to replace inner systematic contradiction with outer, external oppositions” (p. 371).

Engeström and Sannino (2011) clarified their position on the philosophical concept of activity contradictions, “[these] should not be equated with paradox, tension, inconsistency, conflict, dilemma or double bind” (p. 370), and they supplied linguistic cues to separate the forms of contradiction manifestations (Figure 6).

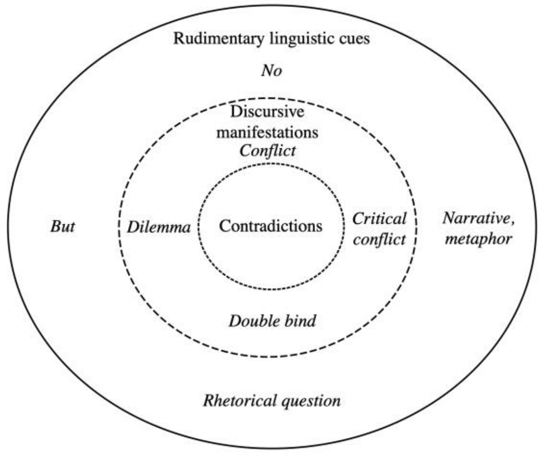


Figure 6. The methodological onion for analyzing the manifestations of contradictions in discourse data (Engeström & Sannino, 2011).

For example, when a teacher states, “We want to teach using inquiry *but* we are limited by the curriculum and class time,” the manifestation is a dilemma (Engeström & Sannino, 2012, p. 370); evidence of a level 1, a primary inner contradiction of either the subject or community node (Engeström, 2015).

The context of this study, remote teaching and learning, requires a significant amount of technology and new tools. According to Murphy and Rodriguez-Manzanares (2014), the introduction of new technology can be problematic:

> Activity theory provides a systematic and holistic perspective on how and why technology can change learning. Central in the activity theory approach is the principle of contradictions and disconnects. Such disconnects occur when new technologies are introduced into practices of teaching and learning that are entrenched in centuries-old traditions and resistant to change (p. 13)

The new tools, technology, and remote context may further confound teacher efforts.

Expansive Learning

The teachers of this investigation used a new reported form of instruction – remote science inquiry instruction (Wells et al., 2022). Teachers' professional learning, especially collaborative learning that questions practice such as LS (Lewis, 2016), parallels expansive learning as it "focuses on learning processes in which the very subject of learning is transformed from an individual to a collective activity system or a network of activity systems." (Engeström, 2016, p. 25). "The key indicator of expansive learning is the expansion of the object of the activity system involved in the learning effort" (Engeström, 2015, p. 7). For example, Augustsson's (2021) change laboratory intervention with teachers in a participatory design project utilized the seven learning actions (Figure 7).

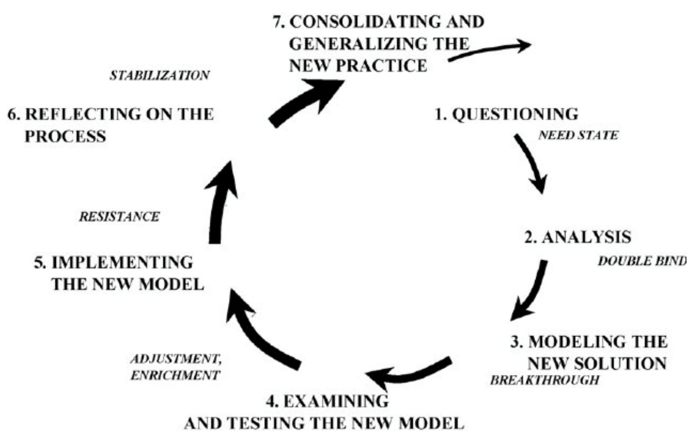


Figure 7. The strategic learning actions and corresponding contradictions in Engstrom's expansive learning cycle (1999b).

However, a change laboratory intervention is not a requirement for expansive learning. Engeström considers schooling "a subject-producing activity and traditional science is essentially an instrument-producing activity"; however, expansive learning activity is unique and "is an activity-producing activity" (1987, p. 125). In a review of the expansive learning process, Engeström and Sannino (2011) summarize the significance of connecting networks and individuals to map learning and expansion to and beyond the zone of proximal development:

> The theory of expansive learning focuses on learning processes in which the very subject of learning is transformed from isolated individuals to collectives and networks. Initially individuals begin to question the existing order and logic of their activity. As more actors join in, a collaborative analysis and modeling of the zone of proximal development are initiated and carried out. Eventually, the learning effort of implementing a new model of the activity encompasses all members and elements of the collective activity system. (p. 6)

The Zone of Proximal Development and Expansion

Vygotsky's zone of proximal development (1978) arose from his examinations of school learning. He defined the zone of proximal development as "the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). According to Wertsch (1985), the zone of proximal development was motivated by Vygotsky's examination of child intelligence and the processes of instruction where "proximal development is jointly determined by the child's level of development in the form of instruction involved" (p. 71). Vygotsky (1978) prognosticated that "[t]he zone approximal development can become a powerful concept in developmental research, one that can markedly enhance the effectiveness and utility of the application of diagnostics of mental development to educational problems." (p. 87). The zone of proximal development factors in the developmental changes during expansive learning (Engeström, 1987, 2015), such as changes due to the contradictions of online LS (Huang et al., 2021b).

CHAT Teacher Research: Contradictions and Mediation during Expansive Learning

CHAT has been used to examine communication technology innovations such as Computer-Based Learning Environments (Blanton et al., 2001; Russell & Schneiderheinze, 2005), and a review of classroom research by Nussbaumer (2012) found CHAT usage "has dramatically increased in education research over the last two decades" (p. 37). Roth et al. (2009) proclaimed that CHAT would reinvigorate science education, noting five categories in particular that CHAT would foster:

> (1) understanding tool mediation in teaching and learning;
> (2) making visible normally invisible structures, processes, relations, and configurations;
> (3) Investigating issues concerning a larger system or across systems;
> (4) rethinking and empowering science learning; and
> (5) creating structures and collaborations to facilitate change. (p. 145)

Several of the above categories, most often 1 and 2, are present in science teacher research, either through action research or LS and are described below. As Roth et al. noted, the CHAT framework of Engeström (1987) reveals fine details of teaching and teachers' actions, including contradictions, mediation, and expansive learning.

Contradictions and Mediation – Local Studies

Researchers who examined teacher action research from the same provincial context as this study reported contradictions, mediation, and expansive learning. Goodnough (2016; 2019) studied K-6 teachers who were part of a large action research project focused on increasing student engagement with STEM inquiry lessons. Teachers of both studies completed multiple cycles of action research, and the pedagogical inquiries resulted in contradictions. For example, the "contradictions in their activity system engage the teachers in doing things in new ways, which resulted in changes in their thinking and practice" (2016, p. 760). However, Goodnough found that addressing contradictions benefited from “a range of supports which were offered through an approach to her professional learning that was teacher-centered, goal orientated, and systematic.” (p. 763). These contextual learning factors were present in Goodnough’s (2019) examination of three primary teachers during three action research cycles. The analysis revealed:

> … systems are often in constant flux as a result of dialectical forces that emerge through the interaction across it within the components of an activity system. Identify these forces in addressing the resulting contradictions are necessary for change to occur. (p. 377)

In another local action research study with two grade four teachers (Goodnough & Murphy, 2017), the participants engaged with technology and expanded their tools, including the use of action research as a psychological tool when they “learned how to identify an area focus, how to plan, formulate research questions, and how to collect and analyze data and relational questions.” (p. 69). Other tools included Screencast-O-Matic to “record videos they created related to various curriculum outcomes” (p.71). Later, these teachers constructed Screencast-O-Matic recordings as informational video clips to scaffold inquiry tasks; as psychological tools that mediated student activity for flipped classrooms (Goodnough & Murphy, 2017).

In 2009, Murphy and Rodriguez-Manzanares published a study of expansive learning with 13 e-teachers from CDLI; these teachers were similar to the subjects of this investigation (high school e-teachers with a significant amount of face-to-face classroom experience). In their study, Murphy and Rodriquez-Manzanares (2009) contrasted face-to-face teaching with the relatively new e-teaching experiences of the 13 participants. One teacher noted that his online instruction experience had enhanced his “techniques of engaging students,” while another commented, “I’ve become more of a facilitator” (p. 8). These teachers experienced expansive learning and as one teacher pointed out, “no one had a roadmap to follow, nobody had firmly established their routine” (p. 9). As a result, their e-learning instructional improvement was an “expansion of the object of the activity system involved in the learning effort.” (Engeström, 2015, p. 7).

Contradictions and Mediation - National and International Studies

Lewin et al. (2018) found contradictions in developing teachers’ digital pedagogy using learning design for lesson planning. Learning design is “a means of formalizing technology-enhanced activity design [and] can support teachers to develop digital pedagogy” (p. 1132). The learning design developmental work spanned four years and included 15 European countries and over 500 teachers. The project produced a digital tool kit designed for practitioners with five toolsets, “each with suggestions for workshop activities that support scenario and learning activity development, together with guidance on piloting and evaluation” (p. 1134). A seminal goal of the developmental work was to “ensure that learners make more effective use of technology in the classroom in order to enhance their learning” (p. 1136) by shifting the activity system towards learning design lesson planning. Their work was ambitious as it was implemented in 15 different European countries and involved over 500 teachers. However, Lewin et al. reported issues such as “lack of time (due to competing pressures arising from interrelated activity systems) and the difficulties of working with complex artefacts” (p.1139).

Lee and Tan (2020) used the Leont’ve three planes of abstraction (operation, action, and activity, Figure 3) to examine teachers’ discourse, learning practices, and activity systems during LS. The group, called the professional learning team, conducted two cycles of LS and found at the plane of action that time constraints led to disturbances in teacher learning due to the "focus on logistical issues, rushed discussions, and struggles with notetaking" (p.9).

Finally, during action research, DeBeer (2019) examined a high school biology teacher and students that compared second-generation activity systems that varied at the "tool'" node. The teacher's motive for the action research was to enrich her instruction to address conflicts with student feedback related to the use of boring "chalk and talk approaches" (p. 396). The boring student system's tool in the analysis was teacher-centred instructional strategies such as "PowerPoint approaches in teaching DNA." In contrast, the tools of the new system were hands-on work in a DNA lab "engaging in PCR [polymerase chain reaction] and blast work" (p. 400). The differences in student outcomes were stark – lectures bored the students, while the barcoding activity taught students to "appreciate the role of DNA Barcoding in solving authentic problems" (p. 400). For students' learning outcomes, psychological tools can make a difference.

Technology-Rich Contexts – Tools and Instruments

This is a remote or distance study and, thus, depends on technological instruments and their psychological tools. In discussing hypermedia and distance learning, Geist (2008) suggested the computer can be a knowledge generator, but within this study, the computer is defined as an instrument (Vygotsky, 1978). That is not to question that distance learning with hypermedia and other graphical applications "allow flexible access to different and unlimited sources of information and multi coding of information as compared to traditional learning means." (p. 111). Azevedo et al. (2010) examined cognitive and meta-cognitive processes during student self-regulated learning hypermedia environments and reported that hypermedia could act as a learning tool; however, measuring the mental impact of the self-regulated learning is challenging – certainly beyond the scope of this investigation. Geist (2008) sees the computer as a psychological tool when using the computer to run programs or interactive simulations to visualize digitalized material, as produced by the interfaces examined within the present study. However, Geist warns, “The introduction of the object in the learning activity itself must be meaningful” to guarantee that the learners’ experience is relevant (2008, p. 114). Within the parameters of the present activity study, the examination of teacher and student actions creates a focus to determine if the tools “principally enlarge the possibilities of thinking” (p.111).

Methods

Case Study

Merriam (1998) defines a case study as an intensive, holistic, descriptive qualitative analysis of a “single unit or bounded system” (p 12) where the case is a “thing, a single entity, unit, around which there are boundaries” (p. 27). This CHAT analysis uses case study data from a group of three teachers (the author is a teacher and university researcher) conducting a remote LS supported by a District Administrator and retired distance education teacher, as they conducted remote LS. This case study data seeks to “capture the ‘rules’ of behaviour, such as the informal relationships among teachers” to construct an account of behaviours in a culture-sharing group using observations, field notes, interviews, and shared documents during LS (Creswell, 2015, p. 466).

Participants

All participants in this case study, including the first author, are experienced science e-teachers for CDLI (Centre for Distance Learning and Innovation - https://www.cdli.ca). University and School District ethical clearance allowed recruiting contact with administrators.

A CDLI administrator consented to our request to recruit CDLI e-teachers (and agreed to be a peripheral participant in the case study). Two teachers, Diane and Norman pseudonyms, consented to participate in the investigation (Table 1). The author, Paddy, and the e-teachers were the LS group. A retired CDLI science teacher with 30 years of experience was recruited as the LS *knowledgeable other*. The CDLI administrator, who had 30 years of experience teaching science that included over 15 years of distance education experience, was not directly involved with the lesson development but provided valuable logistical support, followed the events of the LS in the shared Google folder, and then joined all participants in the final focus group.

The author is an insider

According to Rogoff (2003), learning as an outsider versus the insider position is challenging as outsiders are newcomers who, "In seeking to understand a community's practices, outsiders encounter difficulties due to people's reactions to their presence (fear, interest, politeness) as well as their own unfamiliarity with the local web of meaning of events" (p. 26). Unlike an outsider, the author has an "understanding of how practices fit together and how they have developed from prior events" (p. 26). This insider position and knowledge helps address the main problems for researching contextualized informal professional learning as identified by Eraut (2004):

- Informal learning is largely invisible, because much of it is either taken for granted or not recognized as learning; thus, respondents lack awareness of their own learning;
- The resultant knowledge is either tacit or regarded as part of a person's general capacity, rather than something that has been learned;
- Discourse about learning is dominated by codified, propositional knowledge, so respondents often find it difficult to describe more complex aspects of their work and the nature of their expertise. (p. 249)

As will be revealed, the nuanced relationship between the author and teachers changed subtly over this investigation (Wells et al., 2022). It was, however, aided by LS structures whose strategies purposefully distributed power and labor (Lewis, 2016).

Research Protocols and Data Sources

Ethical clearance for research during the pandemic required remote research methods. However, remote technology was the standard communication method since the LS group teachers and their students were geographically separated by 30 to 1200 km. Before starting the LS, the teachers of the LS group, including the author in the dual role of teacher/researcher, conducted professional learning for LS and science inquiry instruction. Subsequently, the LS group completed two cycles of LS over 16 weeks to develop a remote science inquiry instruction lesson (Wells et al., 2022).

Synchronous and Asynchronous Remote Data Sources

The LS group used Google Meet for remote synchronous interactions that included two pre-interviews, one PL day for LS, one PL day for science inquiry, and eleven LS sessions (all recorded to Google Drive). There were two teach sessions and the LS meeting breakdown by phase was: 2 study meetings, 5 plan meetings, and 2 reflect meetings. The average meeting time for study, plan, and reflect was one hour. The LS teach phase was conducted remotely in Brightspace, each class was recorded, and only the teachers had access to prepare for the reflect phase (a synchronous experience for the teachers, asynchronous for lesson reviewers). The Brightspace class length was one hour for Diane and 1.5 hours for Norman (the class was extended to teaching remotely for two time zones). The knowledgeable others participated in the

LS - PL, three lesson meetings (2 plan meetings and 1 reflect meeting), and the two-hour focus group. The focus group was the only synchronous participation of the administrator.

Field notes were recorded at all synchronous meetings, and all the participants consented to the video recording of all Google Meet sessions, which were subsequently transcribed for coding in MAXQDA. The Brightspace classes were not transcribed; however, the first author repeatedly viewed the recorded lessons for the production field notes (it is CDLI standard practice to record online lesson for students who miss class).

As stated above, reviewers viewed the Brightspace research lesson of Teach asynchronously. They could repeatedly examine what a teacher experienced in real-time: online teacher and student actions, chat communications, application sharing, and sharing of images. Asynchronous LS collaboration used Google Docs, Jam boards, and Gmail. Direct teacher quotes from the lesson presentations were the sources of instructional data.

Coding and Analysis

The field notes and lesson-related resources, along with the transcribed teacher interviews and meetings, were imported into MAXQDA to examine the LS activities of teachers and students. Ultimately, reading and rereading transcripts and watching and listening to videos lead to open coding. The coding used a priori code categories based on first and second-generation AT model components (Figures 2 & 4). However, repeated reading unearthed a need for more codes to further the examination of activity using the Leont've separation of activities by motives, connecting actions and identified goals and operations with dependent conditions for attaining a specific goal (Figure 3). In addition, words such as problem, help, need, want, and support were used in MAXQDA lexical searches to examine documents for themes that may have been missed by coding with a priori codes. Combined with the axial coding, this reinforced a microanalysis where the examination and interpretation of data (Strauss & Corbin, 1998) supported the following CHAT analysis.

Analysis

This CHAT analysis (Engeström, 1987; Vygotsky, 1978) is organized based on activity revealed during the progression through the LS phases. Preparing a research lesson for student instruction is tantamount to creating forms of mediation – where specific components of the lesson are signs or cognitive tools (Vygotsky, 1978). During the LS phases, the mediating tools or instruments (Vygotsky, 1978, Figure 1) change due to contradictions (Table 3, Engeström, 1987, 2015), impacting the LS group activity (the subject) towards the research lesson (object). Subject activity is impacted by the nodes of the second-generation activity system, including rules, members of the community, and the division of labor (Engeström, 1987, Figure 2); evidence of this multivoicedness is demonstrated in this analysis. For the LS group or the subject of the activity system, the first context was the professional learning sessions, followed by two cycles of LS (Lewis & Hurd, 2011; Lewis et al., 2006). While professional learning demonstrated a conflict common among science teachers, this analysis must first characterize the structure of the activity system by defining the nodes (Engeström, 1987) before addressing conflicts.

The Nodes of the Activity System

The components of the second-generation activity system, or nodes (Figure 4) for the LS are subsequently defined to supply context for the object ontogenesis during the LS. As will be revealed, one notable exception of LS object ontogenesis is found in the division of labor and relates to the tools required for the conditions of the operation of any chosen research lesson object (Leont've, 1981). This occurred on PL day (pre-LS), resulting from the teacher's desire to develop a remote science activity that required sensors and data collection interfaces.

Subject

Three teachers, two CDLI science teachers and the author are the LS group and the subject of this activity system. All the teachers are experienced remote science educators (Table 1). Once the PL day was completed, the author acted as a teacher rather than an advisor during LS and provided an insider's view of the object's ontogeny.

Object

The object of the activity system is the research lesson. The object is the motive for activity (Leont've, 1981) and satisfies the drive to conduct a remote science inquiry with the students. This changed throughout the remote LS. The changes in the research lesson were driven by several forces - the primary force being the subject perceived context of the lesson for the students. Regarding activity theory language, we describe these changes as ontogenetic or developmental changes.

Tools

As stated above, the mediating tools developed as part of the research lesson are described as developed during the LS cycle. The rationale for this decision is that the development was controlled by the LS protocols (Figure 1) for the subject, negotiated psychological tools (signs) that mediate the development of the research lesson or object. The subsequent analysis of the object outlines the contribution of LS psychological tools to demonstrate the bond of contextual factors of the LS cycle with teachers' learning (Engeström, 2001).

Communication Technology Instruments and Signs.

Distance education teachers and students used technological tools, classified as instruments (Wertsch, 1985), to communicate during synchronous or asynchronous instruction. Each remote distance education site and teacher's office was equipped with CDLI computers designated for use by distance education students. Each computer was connected to the internet and formatted with software for word processing, spreadsheets, and the software required for the data collection interface; the student computers did not have webcams. Each CDLI teacher and student had a personal account. They were members of Brightspace virtual classrooms with access to features such as course materials, class recordings (for students who missed a class and LS data), and course mail. Teachers posted information to these sites to support students' asynchronous course activities (the displayed information, such as lab instructions, is a sign and is classified as a psychological tool; Wertsch, 1985). The students and teachers also had district Gmail accounts, allowing them to collaborate using Google Docs and Google Classroom.

The CDLI teachers and the science students at remote schools were supplied with a tool kit that contained Vernier® probes and interfaces. These tools could collect data such as pH, temperature, and motion (constant and derivative acceleration). The interface, computer, monitor, and software are sign-producing instruments; the vessel of the images that constitute the student and teacher psychological tools (Wertsch, 1985). The CDLI computers display data that may be shared using the Brightspace application sharing or downloaded and shared as images or spreadsheets within the computer/data interface software (instruments displaying signs). Before the LS started, the students had yet to use the data collection interfaces and probes to collect motion data.

Community

The members of the community node for the study are set around the persons who interact with the subjects and their contexts. The community members include the grade 10 science students, remote site teacher supervisors, remote site administrators, CDLI staff, and a CDLI administrator.

Students From Remote Sites.

The first and largest group within the community node is the students. Sixty-one students were learning in 2 time zones from 21 unique remote school settings and were members of 4 CDLI distance education Science 1206 classes. The number of students at each remote site varied from 2-5.

Teacher Supervisors at Remote Sites.

Each remote site had a teacher assigned to supervise the classroom designated for CDLI distance education. This teacher could have post-secondary science training, but this was optional for supervising a remote school Science 1206 class. This teacher is referred to as the “one teacher” in subsequent sections.

Remote School Administrators.

Each of the 21 remote schools for the four classes had an administrator responsible for the school staff, students, and logistics. Each principal assigned a teacher supervisor for the CDLI classroom. As a contextual note, most of these principals had administrative and teaching duties due to enrollment.

CDLI Administrator and Staff.

The CDLI administrator was in the province's central region and was directly responsible for the project's CDLI staff and distance education teachers. Two CDLI staff were directly involved with the remote teaching of the research lesson and were in the province's eastern region.

Rules

Due to the COVID-19 pandemic, students in remote schools were required to wear masks in shared spaces, but they could remove them while sitting in class. Masks were worn while conducting the inclined plane inquiry. To reduce sharing of touched surfaces, Norman assigned tasks for the students – one person controlled the motion sensor, one person triggered the data collection, and one person released the "rollie" object from the top of the ramp (this is also a division of labour).

Rules govern teaching online for CDLI, and all students and staff were guided by NLESD (2103) "Safe and Caring Schools" policy 4.5 – Digital Citizenship for the "safe, respectful and responsible behaviour with regard to the use of technology" (p. 12). For synchronous CDLI classes, the students were expected to log into Brightspace at the designated class time. The teacher spoke to the students using a microphone, and all CDLI students had headphones equipped with a microphone. Students, however, would generally use Brightspace chat to communicate with the class and teachers, with private student-teacher questions or conversations communicated via private chat. Accepted protocol for student-to-class communication would start with an invitation from the teachers to write on the shared whiteboard, speak in class through the microphone, or share an application to show experimental results. Students could email images to the teacher, and pending approval, the image could be shared with the class in Brightspace.

Science Curriculum Rules.

The Newfoundland and Labrador Department of Education (NLDE) new science curriculum, including Science 1206, features new Skill Outcomes (NLDE, 2018) with the stated goal:

> Students will develop the skills required for scientific and technological inquiry, for solving problems, for communicating scientific ideas and results, for working collaboratively, and for making informed decisions. (p. 27)

Teaching during the COVID-19 pandemic was extraordinary (Appendix 1), and the district responded by suggesting that teachers shift their efforts to normalizing social aspects of instruction. This resulted in a change from the pre-pandemic expectation for completing the course, including all knowledge and skill outcomes. These outcomes were not necessarily new but were reconfigured into a unit to emphasize the need for activities, likened to the Next Generation Science Standards, Science and Engineering Practices (National Research Council, 2012).

Division of Labor

Conducting a hands-on physical laboratory at a distance was both a logistical and student training challenge. To conduct a lab, students from up to nine separate remote settings must synchronously connect with the Brightspace classroom, operate their apparatus, and collect data. With the extra equipment and software, the lab was unlike a regular classroom connection where students watched the Brightspace whiteboard and answered questions via chat or email. Since up to nine contexts would independently operate devices from the CDLI Lab Toolbox, the teachers believed prior student training was paramount if the lab activity was to succeed.

Subject and Community.

The division of labor varied within the community node and was impacted by communication between the subject and community. Leont've would consider the object focus of activity to be "necessarily connected with a concept of motive" (1981, p. 59), and the CDLI teachers' motive for the research lesson was the use of Vernier® data collection devices. According to Leont'ev, object-required activities answer, "to a specific need of the active agent" and are "the main feature that distinguishes one activity from another is the object" (p. 59). Node-to-node communication and a division of labour occurred when activity towards the *Object* required action to achieve a goal of the subject; however, LS had not yet started, and therefore, the object was not known, nor was the germ cell formed (Engeström, 1987). What was recognized is that the research lesson tool would emerge from the CDLI Lab Toolbox – setting the stage for the first contradiction. If the CDLI Lab Toolbox at a remote site were not fully functional, it would prevent the desired lesson from taking place.

Before the lesson or practice could be conducted, the teachers (subject) asked students at the remote sites to find the CDLI Lab Toolbox and report the CDLI Lab Toolbox status using an equipment checklist (prepared by the CDLI staff). This information was communicated to the CDLI staff, who supplied the required equipment to complete the kits at each remote site (some of which required a ferry ride to a remote island). This request demonstrated further divisions of labour when the students found missing components and some out-of-date probes that required restocking.

The decision can be represented using the hierarchical levels of analysis of Leont'ev (1981, Figure 4). Clarifying the hierarchical levels of analysis at this point is essential for the activity analysis of the object ontogeny. It will include agent activities, termed action, a "process subordinated to a conscious goal" (p.60).

Later during LS, when the object was defined as an inquiry into motion on an inclined plane, the students were also tasked with procuring the apparatus required to make an inclined plane. The students readily accepted this duty, with several school sites reporting students asking maintenance staff and administration for items such as boards, blocks, and objects to roll down the inclined plane.

Subject - Intra-Subject Division of Labor.

As documented in the LS analysis that follows, the experienced science teachers of the *Subject* node collectively made practical and seemingly quick decisions to parse the tasks required for the development of the research lesson (such as the decision to check the status of the CDLI Lab Toolbox). As stated above, the structure of LS was a new psychological tool used to guide the development of a lesson, and meetings had functions suggested by Lewis and Hurd (2011).

A collective logistical decision of the first LS meeting was to rotate the meeting participant's responsibilities. The roles for each meeting, modified from Lewis and Hurd (2011), include meeting leader, note taker, and time monitor/agenda editor. This distributed labour and leadership within the LS group and the formalized roles helped establish expectations for each participant before the meeting. It seemed an effective means of social facilitation as each teacher adopted a professional approach to their role. The rotation arranged the leader as the person who recently checked items off or added to the agenda list – increasing the familiarity with the items that would be addressed at the next meeting. The notes were maintained in a Google Doc, ensuring universal access, and editing abilities.

Functions of the Remote School Administrators.

Each remote school had an administrator responsible for the school and assigned a teacher supervisor for the CDLI classroom. Due to the enrollment, most of these principals had administrative and teaching duties.

Functions of CDLI Staff and Administrator.

The CDLI administrator was physically located in the province's central region and directly responsible for the CDLI teachers and support staff for distance education. The administrator was previously an e-teacher for science; sometimes, he provided guidance and support to the teachers.

Two CDLI staff were logistical and technical support for the remote teaching of the research lesson. These staff members were vital for the technological tools the distance education students use at remote schools. The logistical staff member resupplied each toolbox with required materials such as probes, USB cables, and functioning data collection interfaces. The computer technical support staff was responsible for tools or instruments such as ensuring all the CDLI computers were identical in terms of operating system and programs, that students had peripherals such as headphones (for privately working asynchronously such as listening to recorded classes), microphones for speech communication, and keyboards for typing messages into Brightspace chat.

Summary of the Activity System Nodes

Table 2 summarizes the nodes of the second-generation activity system or the primary unit of analysis for this study (Engeström, 2001). With these components defined, the ontogeny of the object, the LS research lesson, is subsequently revealed.

Table 2.

Summary of LS activity system nodes

Node	Composition and/or Components
1. Subject	The teachers of the LS group (Diane, Norman, and Paddy)
2. Tools	Professional learning, LS Structure, LS meetings, the training hypermedia Google Doc, lesson plan Google Doc, Vernier data collection device output, inclined plane apparatus
3. Object	The remote science inquiry lesson – motion on an inclined plane
4. Rules	LS negotiated norms and descriptions, object-motivated professional collaboration, curriculum outcomes, COVID-19 protocols, etiquette for communication (Brightspace and email), class behaviour expectations (NLESD Safe and Caring Schools policy).
5. Community	Teachers, CDLI support staff, CDLI administrator, knowledgeable other, students, remote school principals, on-site supervising teacher
6. Division of Labor	Rotating roles of LS meetings (LS group), lesson plan Google Doc (Diane and Norman), training hypermedia Google Doc (Paddy), lesson observation (LS group), logistics (CDLI staff and administrator), checking tool kits and learning to use equipment (students), building apparatus (students), supervising students at distance education school sites (on-site supervising teacher and administrator)

7.	Outcome	The object or research lesson was developed to support a remote student inquiry for motion on an inclined plane. Once the lesson was presented, there were many outcomes.

The Ontogeny of the Object – The Development of the Research Lesson

Ontogeny of the motion on an inclined plane lesson is the path that includes professional learning and four LS phases. The research lesson Object is the focus of the lesson study, like the science research lessons reported in the literature (Dotger & Walsh, 2014; Kolenda, 2007; Maguire et al., 2010; Ogegbo & Gaigher, 2019), and considers student thinking and difficulties during lesson development. During LS, the subjects selected a unit of study during a curriculum analysis, chose a lesson within the unit study, developed the lesson while considering curriculum outcomes to be evaluated, taught the lesson while collecting student data, and collectively reflected before the lesson was retaught (Lewis & Hurd, 2011). This activity theory analysis of the research lesson ontogeny will bring attention to the forces, such as motivation and contradictions, within and between the nodes of the system (Figure 4) that impacted the research lesson's ontogeny.

Professional Learning Reveals a Science Teacher Contradiction – The Time Dilemma.

An essential part of the teacher's professional learning was sharing science teaching beliefs during a theoretical examination of scientific inquiry using Banchi and Bell's, *The Many Levels of Inquiry* (2008). Each of the LS group teachers was an experienced remote and face-to-face science teacher. The remote session's Jam Board discussion broke the ice by asking questions such as: What are your impressions of the levels of inquiry as defined by Banchi and Bell? Have you taught students using four levels of inquiry or a mixture of levels? How important is some form of inquiry for your teaching? Jam Board posts revealed that Norman and Diane had a strong knowledge of scientific inquiry and preferred “engaging students with questions and to question” (Diane). At the same time, Norman stated, “It [inquiry] should probably be more important than it actually is.” These comments prefaced contradictions of instructing science with activities. Diane’s inquiry questions comment ended with, “But time is the factor as to how many you can actually actively answer…” and Norman added, “In my mind, there are actually too many constraints that keep me from doing what I would like to be able to do.” Many science teachers faced this “time contradiction” (Bevins et al., 2019; DeBeer, 2019; Furtak, 2006) that pointed to a perceived excess of curriculum-defined work within the teaching time provided. The time dilemma or paradox (Zimbardo & Boyd, 2008) is paramount in many teachers' minds when they commit to professional learning – especially LS, as there is an expectation to follow a framework for phases and meetings (Lewis & Hurd, 2011; Lewis et al., 2006). There was added uncertainty when conducting a remote science inquiry with multiple geographically unique sites. Further, reported inquiry-specific pressures of increased workload (Harris and Rooks, 2010), the time required for implementation (Dunkase, 2003), and the lack of control of independent learners (DiBiase & McDonald, 2015; Harris & Rooks, 2010) contribute to the myriad of potential problems that must be considered when embarking on the creation of a remote inquiry lesson.

Lesson Study Structure and the Time Dilemma.

The formal professional learning for LS reviewed the four- phase cycle (Figure 1) the teachers followed to create a teaching episode, termed the research lesson (Lewis et al., 2006). The teachers examined these phases and processes within, using Lewis & Hurd (2011) and online resources from the Mills College, *The Lesson Study Group* website (https://lessonresearch.net). After reviewing LS documents and resources, the LS group discussed LS as a form of teacher research. The staged and formalized procedures of LS created internal contradictions within Norman personified teacher angst regarding the time contradiction by asking about weekly meetings, “I'm just looking for a timeline. And so, does this all take place before we do the actual thing in the classroom? How does the schedule of this work?” He added later, “We don't have a whole lot of time; this is ticking here.”

Norman started a LS group professional learning conversation with a direct question about LS that was both pragmatic and logistical, revealing an inner contradiction, “So, can I ask a question? Because I look through this presentation and, well, the eight weekly meetings… So, does this all take place before we do the actual thing in the classroom? How does the schedule of this work?”

Paddy responded, “Well, that's what we're going to determine Norman, but eight meetings, is a, is a lot.” Regardless of the supplied substitute time to conduct the meetings, Norman had more specific time concerns directly related to LS, “We probably should only look at one cycle, if we look at the statement in the presentation, it says do two cycles. And so, again, looking at the time, I was just wondering how we were fitting it all in?”

Paddy informed the group about action research conducted with larger school-based groups of five to seven experienced high teachers and that one hour was not necessarily required. He described a previous collaboration experience where experienced teachers resolve issues quickly (see Wells et al., 2017), while development proceeds slower when you have “novices who have been in their first- or second-year teaching on your team…they don't know the curriculum and they are not experienced with students."

The LS group discussions of LS strategies and structure continued for 25 minutes then the members of the LS decided to break and review the Mills College resources and the first three chapters of *Lesson Study: Step by Step* (Lewis & Hurd, 2011). After the break and further review, the group followed the LS phase actions and operations of Figure 4, which determined the focus of lesson study meetings for study, plan, teach and reflect.

Selection of Instruments for the Research Lesson.

While completing the LS professional learning session, teacher technology concerns usurped the formal start of the LS; the Lab Toolbox was prominent in the minds of the teachers. Each remote school serviced by CDLI has a Lab Toolbox with Vernier® equipment: multiple sensors and an interface that connects with the CDLI computers. Diane was motivated to learn how to use the Lab Toolbox and expand her skill set, "Norman, I know you have more experience, but I'd be really interested. How do we, how do we get there?" Diane wanted to develop her skills and was worried about school support. Norman was experienced and expressed that "the biggest trick is going to be getting them to actually make the equipment function." For the LS, the selection of one lesson would be difficult. However, one decision was made before any formal lesson study meetings: the inquiry would use the CDLI Lab Toolbox box found in the remote schools. From this point onwards, amid the professional learning session, the teachers started to negotiate how they wanted to teach and what unit they would like to examine; they spontaneously started parts of the study phase of LS, and the discussions changed course toward curriculum, technological, and logistical issues that would limit a lesson.

The Study Phase of Lesson Study - The Object Germ Cell and Shaping the Object's Image

The previous decision to focus on Vernier®, and the time of the school year, created a dilemma regarding the choice of unit of study, Motion or Ecology, for the LS teacher research. During the first study meeting of LS, the Object was unknown. It was part of the LS protocols as the teachers examined the curriculum to determine the unit of study (Lewis et al., 2015). Norman suggested some limitations imposed by the Sustainability Unit (termed ecology):

> If we want to go the ecology route, the only things we really have, we have a pH sensor, which looks pretty good, and we also have the temperature probes so that we could easily do both those things, especially going indoors and doing something like that…But with the with the motion sensor, I think it's got to be acceleration, which is coming up in the physics. (Norman)

When asked about her preference, Diane related her trepidation about using the data collection tools remotely and described past restrictive practices and lack of remote school support:

> I can tell you that in the past we've, because of the time crunch we often get in CDLI, and with 1206, and because of trying to get the kids to actually set up Vernier and having the school support, most times if we do it as a demo. That's how it's done. Most times the kids are given data and said, "Go and graph it." So, my learning curve to actually use this stuff, to do it, would be huge. (Diane)

While Diane seemed motivated to learn new skills for instructing an inquiry where the remote students are collecting data in their school's distance education classroom, she was concerned that the lack of on-site support of the remote school would hinder the data collection by the students; this conflicted with her "goal" of her envisioned teaching "action" that was a hands-on student inquiry (Leont've, 1981). Norman then vocalized his choice of unit dilemma by adding, "I don't think the Ecology Unit will be an easier one to put it in, to be honest, just because the equipment simpler." This turned the negotiations back to the unit of study, and Norman continued, “I don't know what exactly the lab is that you could use it within the ecology unit. So, I don't know, Diane if you can give me some input on that one or not?” Diane responded, “I have to review that unit again because like you, this is my first time through the re-jig.” The term “re-jig” is a colloquialism for the recent changes to the curriculum that include the addition of an Integrated Skills Unit (NLDE, 2018).

The Object Germ Cell and the “One Teacher” Contradiction.

Once the LS group decided the unit of study was Motion (NLDE, 2018), the LS meeting transitioned to start the LS plan phase and decided the research lesson would examine motion on an inclined plane (see Wells et al., 2022). Thus, object ontogenesis commenced from the point of the remote motion activity, and research lesson germ cell was formed (Davydov, 1982; Engeström, 2015). The conversations below capture some of the teacher logic of the first LS plan meeting that formed the germ cell:

> Norman started with a question, “We're just about halfway through the physics now, do you think it's worth your while to try and invest in the physics unit one?” He was referring to the core motion activities (NLDE, 2018), and the consensus was “yes,” The meeting quickly changed focus to shaping the type of motion activity.
>
> Diane asked, “are we talking acceleration… or doing like an activity with the three graphs, or would that be an intro activity?” She continued, “So what if we use the Vernier… to help them visualize because they actually see the graphs being made?”
>
> Norman responded. “Well, I think you could easily. If we can make it work on our own and we could easily fit into the position time graph section, to at least give them [the students] an idea of how Vernier should work and give them results.” He finished with, “Then you can go do your acceleration learning inquiry, or whatever you want to call it, for the lesson study.”

These interactions shaped the object and revealed teachers' motivation – Diane wanted students to connect the motion down the inclined place with simultaneous graphed motion and Norman wanted them to see results as a position time graph. Both teachers tacitly recognized that the combination of observed object motion and graphed results from the data collected by the interface tool was a psychological tool that could support student learning. The teachers' science inquiry motivation was evident in teacher pre-interviews. Diane was "really excited to learn a bit more about Vernier because it's a tool I have not overly used." Norman indicated he had experience with the Lab Toolbox Vernier® interfaces and probes and wanted to use these for the inquiry as "these types of learning and activities [are] extremely important." The teachers remained motivated to conduct a remote inquiry involving motion and to have students use data collection interfaces; however, within a previous conversation is a contradiction, "the biggest trick is going to be getting them to actually make the equipment function" demonstrates Norman's foresight for student training for the required skill to use the data collection interface. This contradiction would manifest in future LS meetings by creating goals requiring action and from teacher-predicted student conditions requiring operations (Leont've, 1981).

This germ cell conversation during the study phase was pivotal. From that point onwards, the LS group was object-focused and directed activity toward their motive of conducting a remote science inquiry instruction lesson (Wells et al., 2022). In the fast-paced negotiation that follows, the LS group members talk their way through the confirmation of the topic of the research lesson and, consequentially, the unit of study.

> Paddy: If we're going to go for it, just start to look at what curriculum is there, and the challenges. You know, follow the lesson study model and look at what challenges you think the kids are going to have and how to best use the Vernier to help them understand what acceleration is…
>
> Diane: Are we talking acceleration or doing like an activity like you say with the three graphs, or that would just be like an intro-activity?

Paddy: You could do it if you wanted to. You could do the intro-activity that I talked about, like ‘make the graph’…then automatically you've introduced kids to the two graphs because they'll have the DT [distance time] on top and the VT [velocity time] on the bottom…

Diane: Yes, our next section Norman, after velocity, is getting into the graphing, right?

Norman: Yes.

Diane**:** So, what if we use the Vernier, what if you use that as the way to help them visualize, because then, they actually see the graphs being made?

Norman: I think you could easily, if we can make it work on our end, we could easily fit it into the position time graph section to at least give them an idea of how the Vernier should work and should give them results. And then you can go on to do your acceleration learning inquiry…the lesson study… I think maybe use the position time graphs as a place to...

Diane injects: As an intro.

Norman replies: To how to use the Vernier!

Paddy: … So, if you wanted to do...a demo to demonstrate that, and then that helps us get ready for doing the real lesson study lesson, which is later when you do acceleration.

Norman: I think that would be good because like I said, I think really one of the obstacles is going to be making sure that each school and each place is able to get their equipment up and running the way that we need them to have it up and running at the top level… I don't know what familiarity this one teacher has with setting up the Vernier or making them go right. So, these are these are going to be the issues that I see is coming.

The speed with which the object image comes into focus, less than thirty seconds, demonstrates the level of expertise of the teachers and their motivation to engage students at the remote sites with a hands-on science inquiry. As the image of the object takes shape during the ontogeny, up to and beyond the research lesson enactment with remote students, the teachers encountered contradictions that result in tool production.

The "One Teacher" Contradiction

A significant comment from the above interaction requires attention. When Norman mentioned the "one teacher," he discreetly and implicitly noted a concern that would need to be addressed by the object-research lesson. Diane indicated this previously in her concerns about remote student support. In each remote school, a teacher is designated to supervise the CDLI distance learning classroom. At the same time, students are logged in for synchronous or asynchronous learning through the Brightspace course shell, Norman's "one teacher." This teacher could be a specialist from any subject area and is not required to know how to use the CDLI Lab Toolbox or understand motion (kinematics). Since the CDLI teachers of this study instruct students from 21 remote distance education school sites, the notion of training over 20 teachers was daunting. This contradiction would shape the object in future LS plan meetings.

A Unit of Study Selection Shapes the Object and Focuses on a Topic of Interest

The above conversation/negotiation was a pivotal moment from an activity perspective. The unit of study of the research lesson would involve the Motion Unit and be, at that time, a student examination of acceleration and graphing. The tools that students would be used to conduct the lesson were the Vernier® interfaces and motion sensors from the CDLI Lab Toolbox. These decisions did not change the phase of LS – technically, the phase was study, though some of the LS - PL had yet to be completed and reviewed; however, much of the activity and actions that follow, and the resulting contradictions, are shaped with the chosen object-focus in mind, driven by the motivation to conduct a remote hands-on motion lesson. Potential contradictions that confront teacher motives were voiced as concerns by Diane and Norman, who both want training and to train their students to use the software and hardware required for the investigation; envisioned as action requirements towards the goal where remote conditions would require student operation of the Vernier® interfaces and motion sensors (Leont've, 1981). Once the research lesson focus was selected, signifying that the unit of study was chosen, the LS group formally examined the curriculum.

The start of the LS study phase and the later transition to the plan phase was organic and driven by teacher interest in conducting a remote inquiry. The pragmatic teachers seemed interested in identifying barriers or contradictions, knowing that without the equipment, software, and training support, regardless of the unit of study for LS, it would consume time if the desired Vernier-based inquiry lesson was to proceed (a Toolbox double bind).

Software and Hardware Uncertainty

Still, within the study phase of LS, discussion topics changed rapidly as the LS group negotiated technology requirements and the unit of study simultaneously. The LS group changed topics to discuss software – yet another issue to consider for remote students conducting an inquiry. Paddy's computer had a version of this software reported, "If you plug in your LabPro and your Logger Pro is turned on, it should just recognize the LabPro." This created uncertainty for Norman, and he stated, "We don't have Logger Pro on our computers. At least I don't. I don't know if you have it on yours." Diane replied, "I have it on mine!"

The discussions focused on how the software was installed on the CDLI distance education computers in remote schools and the versions that should be present. The group was aware that all versions of the data collection interface work with the software; however, they are still determining what interfaces are in the schools. Norman reported, "I've seen different motion sensors." These two sensors have different connectors, and one requires an adaptor. It should be noted that Vernier Science Education (https://www.vernier.com) has a history of commitment to supporting their devices and software, regardless of the generation. Older probes and interfaces (LabPro®) and new and recent interfaces (such as LabQuest3) would be supported. However, further equipment uncertainties created contradictions that must be addressed to ensure all students can collect data during the research lesson.

The Study Phase of Lesson Study – The Object is Defined

In the first official study meeting for LS, the teachers selected a lesson from the unit of study. This conversation is summarized below and is the moment when the image of the *Object* was clarified.

> Norman: It's called position time graphs for accelerated motion. OK, that's what this is. Well, page 247 in a textbook or something like that and is determining instantaneous velocity using tangents.
>
> Diane later added, after some searching, "Well, [page] 246 is the start of the section."
>
> Norman: … if we can get them to make some sort of a curve that was reasonable with the motion detector and the Vernier equipment, they should be able to print off their graph from Logger pro and use that to calculate instantaneous velocity, which I don't feel is impossible. But I feel it's a worthwhile experiment to try.

After discussing printing technical issues, they returned to the data collection and presentation; it was evident that the teachers needed to be more confident with remote student use of the data collection tools.

> Norman - I think the issue is, I don't know whether we can actually get a graph that's going to be reasonable?
>
> Diane - … So, what if have you have the student data? They'll have their graph, but we'll have to have some, like...
>
> Norman - Yes, we might have to have a backup plan or something like that.

Diane - Well, they analyze their graph, but we have a graph that they also have to analyze.

Norman - Ideally, yes. Ideally get something to work. I'm thinking like when I've done this before or something similar to it, you just add the slight incline plane or something like that, and you roll the basketball down or roll the motion cart or something like that. And you get your curve from that because everything should be a nice, smooth thing and you should get it not too fast, but they should come out with reasonable. A reasonable facsimile of error, something that they can use. That's my guess. Well, I don't know how it will work nowadays. I haven't done it in about six or seven years, so I've got no idea if we'll make it work. But I do think it's possible and I do think that it's relatively easy for most schools to set that up. I don't think it is really complicated. All you need is a board, right? A board and something that'll roll.

This conversation demonstrates what is termed the *Toolbox double bind*. Gathering the instruments is not a complex operation – the administration and supervising teacher (the *one teacher*) at each remote site can support this student endeavour. Undoubtedly, the teachers want the students to use the Toolbox to conduct a remote lab; however, the subject perceived two time-contradiction choices: coordinating and then training students and the *one teacher* to use the Toolbox or the production of new resources to ensure the students can independently use their Toolbox equipment to collect the necessary data during the investigation. It is assumed that *one teacher*, physically present at each remote site, cannot assume the responsibility, nor have the expertise, to train the students to collect motion data. Norman stated the need "to have a backup plan or something like that" but the teachers did not want to give the students data. The thought of depriving students of the observation experience – to observe changes in a graph while rolling an article down an inclined plane, seemed counter the goal of their lesson development actions. This *Toolbox double bind* is like Mendeleev's time-consuming double bind (Engeström, 2015) during the construction of the periodic table, a result of "the contradiction between the new rule and the old instruments" (p. 210). While not at Mendeleev's level, the contradiction between the new rules and old instruments would eventually be resolved; however, in this instance, the new rules for *Toolbox double bind* required the production of psychological tools to support the use of Toolbox instruments.

The conversations then turned to logistics of the technology and science equipment – manageable contradictions that, when resolved, reduce the zone of proximal development of the production of the psychological tools.

> Norman - I think like most schools, no matter how small a school, they're going to have a basketball or some sort of ball in the gym. And that should be workable to use. It should be large enough that it'll pick up. It should be as long as they can get it rolled on the board or whatever. All that should be workable.
>
> Paddy - All right. So, I think you're right. I think the thing we need to do is make sure that they can print a page.

Later Diane confirmed printing was possible "I've done it in the past when I've done sessions at the schools." Next was the naming of the object when Paddy inquired, "What's the official title of the lab from the textbook?" Diane responded, "Using a position time graph to calculate instantaneous velocity." Norman responded, "Yeah, basically something along those lines." That moment in congress, when the research lesson topic was selected and named, formally initiated the ontogenesis of the object – whose image was the motive of activity for the LS group (Figure 5).

Activity and Object Ontogeny

From the moment the object was identified, like zygote formation, it could change and develop due to the activity of the LS group versus genetically controlled mitosis. Ontogeny is a term for developmental changes that occur over the life of an organism and is not always a linear process. For example, cell mitosis, growth, and cell differentiation in human arm development generate the flat distal end of the pectoral limb that is not recognized as a hand until the digits separate through genetically controlled cell death, apoptosis. According to Engeström (2015):

> The object is inherently contradictory from the beginning. Negotiations emerge as shared tools and concepts are built to depict and handle the contradictory object and the conflicting motives related to it. The emphasis is on the creation and implementation of foundational germ cell models for new patterns of the activity. (p. xxxii)

The developmental changes caused by contradictions sent reverberations through the activity system of the LS group (subject), impacting the production of mediating tools, the division of labor and the community. The word "reverberation" is intentional, as the components of the activity system are not static or isolated, and their actions or characteristics affect the *Object*. This fits well with Leont've (1978), who believed that an object of activity has an "independent existence as subordinating itself and transforming the activity of the subject" (Leont've, 1978, p. 52). This activity, actions, and operations will feature in the expansion of the object during the plan phase of LS.

The Plan Phase of Lesson Study – Expanding the Object

Developing the research lesson during the plan phase required the LS group to continue focusing on the students and their context-specific equipment and support needs. Two contradictions from the study phase carried over to the plan phase (the *one teacher* contradiction and the *Toolbox double bind*). Their object expanding solution was addressed in early plan meetings.

Tools Required for Remote Science Inquiry Determined by Conditions and Operations

In the first plan meeting of LS, the group believed the lesson's success required knowing the Lab Toolbox equipment status and student training. Weeks before the meeting, Diane asked some students about the lab equipment and conveyed her frustration with the lack of student responses. "Who's heard of their Toolbox from CDLI? Nobody. Who's heard of Vernier? Nobody." This had spurred her to investigate the Toolbox status, and she noted, "I've had the kids looking around and I got a number of schools who don't have a motion detector in their toolboxes."

Prior to the second LS plan meeting, equipment updates were discussed with CDLI technical staff and the senior administrator. It was the teacher's responsibility to poll their students and ask them to determine the status of the CDLI Toolbox. This included determining if the students required a new motion sensor to complete the lab. Once the status was determined, completing a Toolbox was passed on to CDLI support staff. The CDLI staff were dedicated to, and supported, the replenishment operations for Lab Toolboxes in all schools that reported missing parts, probes, and cords. Most schools that needed updates or replacement parts received them within two days. The remote coastal schools of Labrador and the South Coast of insular Newfoundland, where vehicle access requires a ferry and equipment update journeys require a week.

Mediating tools – developing psychological tools to support student use of instruments.

To support student independence, the LS group met and decided to develop a student training document that included linked videos. The Plan meeting discussed the content and storyboarding required for a Google Doc with hypermedia videos to train the students. Diane sent a list of Lab Toolbox materials that would need to be procured for graphic content for the document and videos. A text message was sent during the meeting. Before the meeting was completed, the CDLI technician reported that all the designated CDLI student computers had the software needed to support the Lab Toolbox. CDLI standardizes the software for the interfaces for each remote school site, and, according to Diane, these computers are reformatted every year by CDLI technicians. The group decided the software status would have to be verified and hardware tested before the lesson was conducted. Below "Activity - Motive" of the layers of analysis of Leont've (1981), the desired software testing activity would require a data collection interface connection to the computer – mandating student training (goal) and production action (making a training hypermedia Google Doc) that requires knowledge of conditions (software, interface, and sensors) for the appropriate tool development operations (Figure 3).

Following the above discussion, the group decided to conduct a teacher Vernier® equipment refresher, to test equipment; this would help support the next meeting three days later that would focus on training the students to collect data with the motion sensor and graphing data with the CDLI computer software. During the equipment refresher, teachers found some equipment issues– a misplaced wire for connecting the motion sensor and the power supply for the interface for one Toolbox, emphasizing the importance of the Toolbox verification by school sites. Class surveys conducted by Dianne and Norman "found most DE [distance education] schools had toolboxes, but several toolboxes were missing the motion sensor" (Wells et al., 2022, p. 16). The polling process also revealed that students might have one of three types of data collection interfaces, each with a unique appearance and port locations to plug in the cables; multiple interfaces are conditions that impact the operation of tool development (Leont've, 1981). The teacher supervisor was an unknown condition in each unique geographic location that could impact data collection operations, as they may be unable to train the students using three unique interfaces. The “one teacher” uncertainty and “Toolbox double bind” impacted student training and lab document production goals. The Subject's motive for student independent data collection was authentic; as Norman summarized, “It's going to be less effective if they have to use a set of data that we just give them. So, I think the whole point is to get them to actually do it.”

Psychological Tools Used for Student Training and the Acceleration Activity

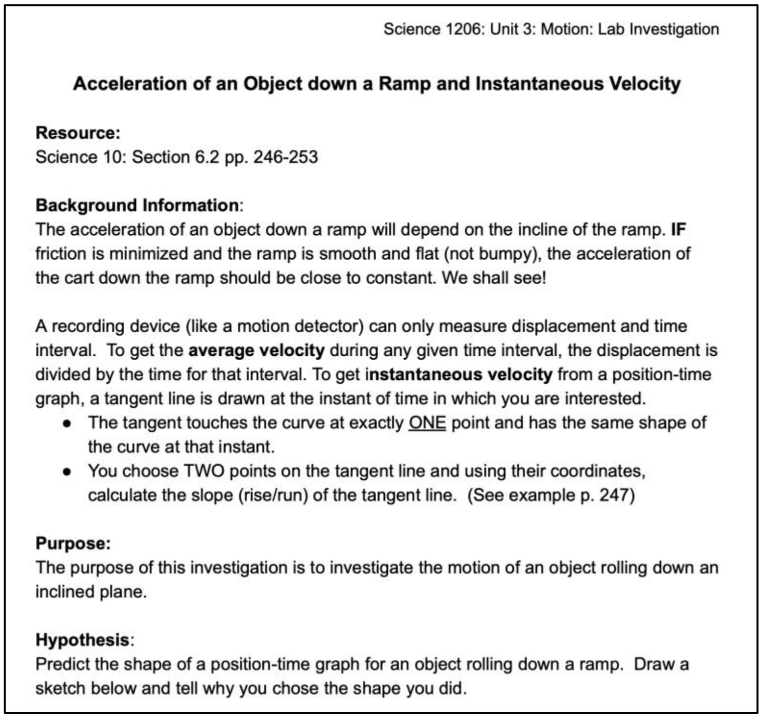
The LS group decided to produce Google Docs to support students’ data collection needs (Wells et al., 2022). Before the acceleration inquiry, the students would use the documents and the videos asynchronously to assemble and test the Toolbox apparatus at the remote sites. Before the formal acceleration inquiry (object), a synchronous training activity was used to verify that the hypermedia Google Doc acted as a psychological tool.

The division of labour to produce the psychological tools was as follows: Diana and Norman developed the acceleration inquiry document with front matter, procedures, inquiry questions, and diagrams of apparatus; Paddy was responsible for the production of the hypermedia Google doc with images of cables, interface and sensors with hypermedia video of connecting the cables, interface, sensors and booting up multiple devices. These resources were tested, reviewed, and edited in plan meetings; portions of the resulting documents are seen in Figures 7, 8, and 9.

The Acceleration Inquiry Document

The lesson document included several features to support the remote inquiry (Appendix 7 for the full document). This was their first formal inquiry that used the Toolbox; the students also needed to construct the inclined plane apparatus. The document contained a link to a video and images of the inclined plane apparatus. Diane and Norman summarized background theory information in the introduction and added a request for a hypothesis (Figure 7, Appendix 8). The request was part of the predict-observe-explain inquiry strategy for the activity (Wells et al., 2022). The teachers predicted the conditions that would confront the remote students and developed psychological tools to support the operations of students who are members of the Community node (and connect with the object). This document has many signs (Vygotsky, 1978; Wertsch, 1985), such as images and text that can support student learning. The teachers' *goal* of supporting student operations in their remote environment (*conditions*) and, to buttress the students in their zone of proximal development, resulted in their *operations* (Leont've, 1981; Figure 3) to add the appropriate mediating signs (Vygotsky, 1978) to the acceleration inquiry document.

It should be noted that the hypothesis that asks for the predicted shape of the distance-time graph for motion on the inclined plane (Figure 7) is a metacognitive tool for the students (Haysom & Bowen, 2010). The predictions the teachers observe are a cognitive tool to learn about student thinking – what they know about graphed motion. Graphing is challenging for students learning motion (Beichner, 1994; Kozhevnikov & Thornton, 2006; McDermott et al., 1987).



Science 1206: Unit 3: Motion: Lab Investigation

Acceleration of an Object down a Ramp and Instantaneous Velocity

Resource:
Science 10: Section 6.2 pp. 246-253

Background Information:
The acceleration of an object down a ramp will depend on the incline of the ramp. **IF** friction is minimized and the ramp is smooth and flat (not bumpy), the acceleration of the cart down the ramp should be close to constant. We shall see!

A recording device (like a motion detector) can only measure displacement and time interval. To get the **average velocity** during any given time interval, the displacement is divided by the time for that interval. To get i**nstantaneous velocity** from a position-time graph, a tangent line is drawn at the instant of time in which you are interested.

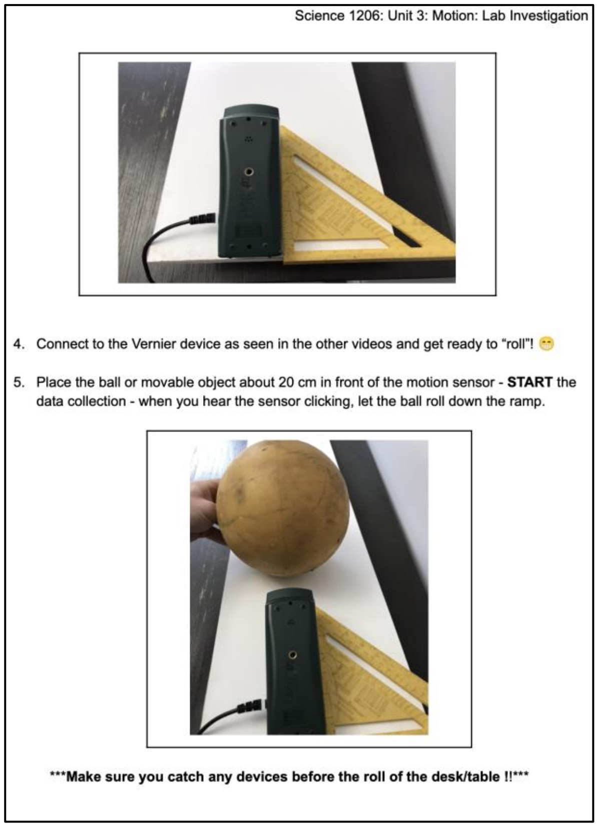
- The tangent touches the curve at exactly ONE point and has the same shape of the curve at that instant.
- You choose TWO points on the tangent line and using their coordinates, calculate the slope (rise/run) of the tangent line. (See example p. 247)

Purpose:
The purpose of this investigation is to investigate the motion of an object rolling down an inclined plane.

Hypothesis:
Predict the shape of a position-time graph for an object rolling down a ramp. Draw a sketch below and tell why you chose the shape you did.

Figure 7. Page 1 of the lab document - Acceleration of an Object down a Ramp and Instantaneous Velocity. This is a psychological tool, and the hypothesis section aimed to provide insights into student thinking and misconceptions.

Page 2 of the acceleration inquiry document provided space for data and graphs. At the same time, pages 3 and 4 (Figure 8) reviewed the process of collecting data while avoiding the errors induced by placing the “rolly object” too close to the motion sensor. The document also suggests to students when to start data collecting and safety considerations for moving objects. All the factors contributing to the production of the document through operations demonstrate teachers’ awareness of the conditions the students may encounter during the acceleration inquiry. How did the teachers come to know these conditions? The teacher's practice with the Toolbox instruments used in the acceleration inquiry early during the plan phase of LS illuminated areas of potential difficulties by experiencing the conditions the students may encounter. The collaborative practice was a cognitive-sensory experience and stimulated the training contradiction. The LS set a goal for student training to achieve the object of their motivation – conducting the acceleration inquiry. This resulted in the *Subject* conducting another motivated activity to attain their object's image - the development of Google Docs with hypermedia for student training.


Science 1206: Unit 3: Motion: Lab Investigation

4. Connect to the Vernier device as seen in the other videos and get ready to "roll"! 😁
5. Place the ball or movable object about 20 cm in front of the motion sensor - **START** the data collection - when you hear the sensor clicking, let the ball roll down the ramp.

*****Make sure you catch any devices before the roll of the desk/table !!*****

Figure 8. Images from page 4 of the "Acceleration of an Object down a Ramp and Instantaneous Velocity" lesson document. Note the suggestions that ensure safe data collection results in graphed acceleration data.

The Google Doc With Hypermedia and Student Practice

As with the acceleration inquiry document, the teachers used their practice experience with the Toolbox to shape their understanding of the conditions faced by the students; this, in turn, shaped their goals for the document action and familiarity with the specific conditions for assembly and use of the Toolbox instruments. Grounded in the knowledge, the teachers could ask: What operations would the Google Doc and hypermedia files support?

The Google Doc with hypermedia (Appendix 9) for student training was tested during the study phase of LS during a motion practice activity. Before the students conducted a “Walk the graph” practice activity, they were sent the link to the Google doc with hypermedia. This document addressed several conditions perceived by the teachers because of the survey of the Toolbox in each remote school site: multiple interfaces and unknown on-site teacher support. The document’s first objective was to help students identify the interface type in their Toolbox using images (Figure 9). Once students identified their interface, they could use linked videos in each section to support the proper connection and usage of the interface and data collection probes or troubleshoot connection errors.

The students used the Google Doc with hypermedia asynchronously in the class time scheduled for conducting assigned work from the Brightspace course shell. The teachers’ synchronous practice sessions before the formal motion inquiry revealed how effective the Google Doc with hypermedia was in supporting remote set-up and usage.

What Vernier interface do you have? The video links below show you the apparatus you need and explain how to set up the interface for collecting data.

LabPro - this device requires a power supply (plug), USB cable to connect to the computer, a cable to connect the probe (motion sensor) and the computer must have a version of Logger Pro. See this document for device cables.
This video demonstrates the LabPro set up and this video shows how to collect motion data.

LabQuest - this device requires a power supply plug but has an internal battery, USB cable to connect to the computer, a cable to connect the probe (motion sensor) and the computer must have a version of Logger Pro. This video demonstrates the LabQuest set up and this video shows how to collect motion data.

LabQuest2 - this device requires a power supply but has an internal battery, USB cable to connect to the computer, a cable to connect the probe (motion sensor) and the computer must have a version of Logger Pro. This video demonstrates the LabQuest 2 set up and this video shows how to collect motion data.

Figure 9. The Google Doc with hypermedia (blue text). The interfaces pictured Once the students identified their interface, the linked videos supported the connection of required cables for probes and the computer for application sharing.

Student Practice – The "Walk the Graph" Activity

The teachers used two strategies for students to demonstrate that they could set up and use the instruments from the Toolbox when moving the motion sensor or during the "walk the graph" activity. Diane tried the former activity, where students were shown a graph of constant motion, and the challenge was to make the shape of the graph by moving with the sensor in their hand – to walk the graph. Diane reported success with the sensors, graph outputs, and students' ability to mimic the motion portrayed on a distance-time graph.

> They're getting really nice graphs but they're, but they're walking… I said set it up… I demonstrated with my camera as I set it up and they watched me walk back and forth and that's what they did. And they're getting good! (Diane)

Norman commented that the Google Doc with Hypermedia and practice "walk the graph activity" were important. Of the Google Doc with Hypermedia, Norman was complimentary, "I think because there were groups of mine who basically had the whole thing hooked up before I even had it shown on screen what was going to go on…everything down together and plugged in" and "they remembered how it worked and what they were going to do." Norman added, "[it] made a big difference to the fact that they were familiar. If we had gone in cold, not having shown them anything, we would have been 20 minutes." The practice was a productive skill learning event for students with some multiple interface issues reported with some remote sites:

> Diane: So now the only one I had problems with was LabQuest2. And I'm not familiar with the LabQuest2 and to help them problem solve it.
>
> Norman: I had one class using the LabQuest2, and the only thing that was weird is that their data, when they sent it in, had the temperature data as well. And I have no idea why they would get the temperature data.

These interface issues were, however, resolved by referring the students to the Google Doc with hypermedia that demonstrated how the motion sensors are connected to the interface (and only the motion sensors). Time again is an essential teaching variable, and the time saved combined with the synchronous and asynchronous training strategy resolved the training contradiction. With the practice success for many sites, the date for presenting the research lesson was scheduled to field test the object in the teach phase of LS.

The Teach Phase of Lesson Study – The Object and the Outcome

During the asynchronous training and subsequent synchronous practice with the tool kit, the students demonstrated the skill proficiency required to conduct the remote inquiry, "Acceleration of an object down a ramp and instantaneous velocity." As the inquiry class started, student engagement was evident when the students completed their *division of labour* operations by acquiring the necessary materials and assembling the inclined plane or ramp at every remote school site (Wells et al., 2022). The responsibility of "building the apparatus and having the physical experience of conducting the lab was important for student learning and engagement" (p. 28). This was obvious in the post-lab photographs of the constructed apparatus– a success on its own. However, the object produced more outcomes that satisfied the subject's motive for the activity. However, a fly in the ointment was runaway object-related conditions that impacted the research lesson (object), where contradictions emerged, resulting in an instructional dilemma.

Inquiry Lab Introduction and Student Predictions

Brightspace is a digital tool (instrument) that supports unique application-sharing opportunities. All students, at home or in remote school sites, connected synchronously in Brightspace during the lesson presentation and could observe and participate in the inquiry lesson introduction, review of theory, and make predictions (See the field notes of Figure 9). While image sharing in Brightspace is restricted for students due to a lack of webcams, application sharing allows all users to see graphical representations of any participant's data collected during student experiments. These images and text are instrument-generated, mediating artifacts used in the lab process as psychological tools (Vygotsky, 1978; Wertsch, 1981). In this regard, the mediating artifacts differ from those used face-to-face (Wells et al., 2022). However, a uniquely remote lesson problem is visual student feedback - exacerbated by the lack of webcams on the student CDLI computers. To overcome this "student feedback condition" the acceleration inquiry document (Figure 7) included a section for student hypothesis (Figure 9). The teachers used application sharing and requested that students draw a prediction on the Brightspace whiteboard. This strategy provided immediate feedback for student thinking while reducing the feedback loop time for correcting student misconceptions.

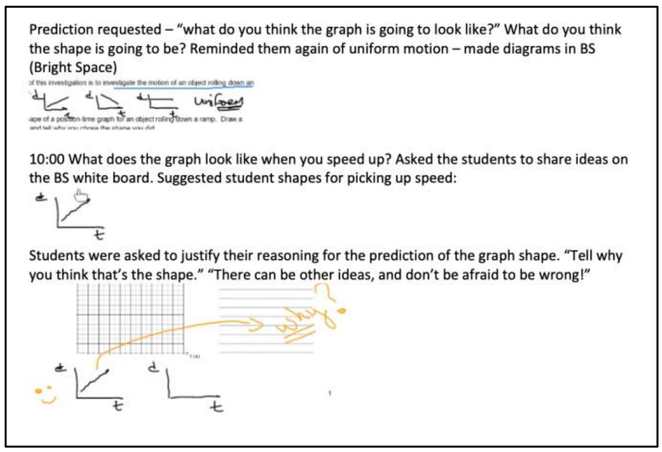


Figure 9. Field notes of Diane using application sharing from bright space to interact with students using the lab document, drawings, her notes, and speech as psychological tools. Texts are annotations of Diane's verbal comments to her students.

Both teachers persuaded the students to draw predictions on the whiteboard space (see Figure 9 field notes). However, the students were hesitant; only ten were bold enough to draw their predictions. Most predictions were incorrect for unknown reasons during the lesson (Figure 10); the handwritten lab reports reviewed later revealed a similar finding.

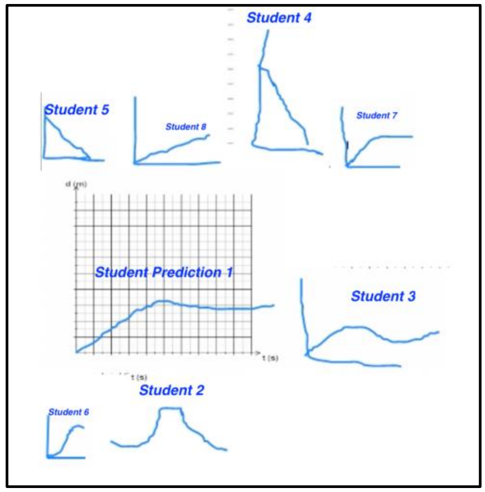


Figure 10. The range of student predictions from the field notes of Norman's presentation of the inquiry lesson. Students 6 and 2 have initial curves that indicate an acceleration in Figure 12.

The lab document and teachers requested a student prediction – once produced by the students, these signs (Figure 10) become a psychological tool for the teachers to assess students' thinking. The teachers addressed these misconceptions during the subsequent data collection and clarified the differences between acceleration and constant motion. Unfortunately, the student thinking that resulted in the poor performance on predictions was not resolved as no students consented to be interviewed for this investigation.

The Student Equipment Access Dilemma

Once data collection commenced, with multiple contexts using instruments to collect data, the teachers' attention was divided as some students could not attend their remote school; possibly related to the pandemic. Regardless of the cause, the teachers were confronted with a difficult choice: send the off-site students a printout of the lab data and focus on the synchronous students or try to manage multiple contexts while acting as a proxy for students without equipment.

The work bench and set up. Reminded the students how to set up the LabPro – total run through for devices and software connection. Showed the setting for the MD2 and how to have it square to the board. Showed the position.

LabPro is set up and connected to computer last with Logger Lt. running – last thing to do is connect the power. Green light and then it “sings” to us.

Constantly checking in with the students to see if they are set up. Check mark if Logger Pro is open.

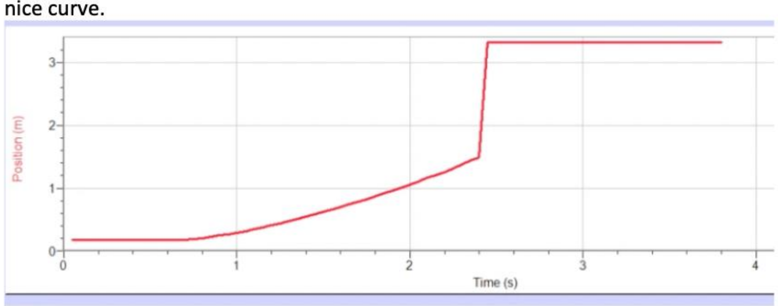
Students with no equipment chose the “rolly object” (Beans, empty can or ball). This engages them with choice. Beans was chosen.

Figure 11. Field notes and Diane’s inclined plane apparatus as viewed by students as she acted as a proxy for students without equipment access. MD2 is the green motion detector at the top of the ramp.

Both teachers chose the latter and included these students in the data collection. Teachers streamed their setup via webcam (Figure 11) and asked the off-site students to guide them with instructions in the Brightspace chat. The teachers manipulated the instruments on behalf of the students, choosing the object to roll down the ramp on video, and the students typed, “Go!” The rolling object’s motion was visible on the video feed, while the shared application produced a motion graph (Figure 12). This supported the teacher’s goal for all students to see object motion as the graph was produced simultaneously.

Asked students by name if they got similar graphs. They said "yes" and some started to change the angle of their ramps. The students who changed the ramp were applauded by the teacher – "that's science – super!"

Second ball attempt produced a "great graph!" "That was an awesome one!" The graph had a nice curve.



Do you want to try the empty can? We needed two graphs, two graphs per group to show movement down the ramp. Also – a picture of the set up.

Figure 12. An image is taken from lesson field notes as Diane interacts with multiple remote contexts, saying "yes" and "that's science – super" while proctoring other students without equipment access. The distance-time graph above was produced while the object rolled down the ramp (inclined plane).

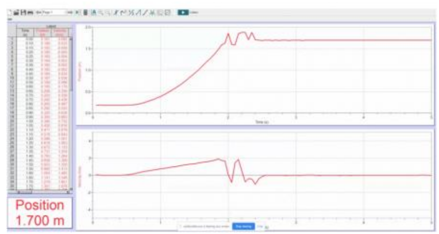
The field notes, seen in Figure 12, offer examples of the verbal feedback supplied by teachers while they proctored for off-site students. These were conveyed to students during the teacher-proxy operations guided by student communication in chat (demonstrating the teacher's ability to communicate effectively with multiple remote contexts). Diane also used the graphs produced during the proxy operations as an example for remote school site students. This process was similar to Norman's experience – using psychological tools such as graphs produced via proxy data collection to support a few students unable to use the equipment.

Norman was more explicit in his instructions (Figure 13) and conducted a different version level of inquiry termed confirmation inquiry; Diane conducted a structured inquiry with her students (Banchi & Bell, 2008).

Norman taught in two time zones and conducted proxy operations like Diane for off-site students. Towards the end of a busy lesson, this was recorded in the fieldnotes from Norman's lesson:

> Data collection for students without the lab pro at home was complete and he moved on to troubleshoot for students working in schools. Asking students by name "______, did you get it to work?" "______, did you get data?" "______, did you get things to work? Perfect! That's all I wanted to know."

He gave a demonstration of how to collect data properly with the ramp cart – ensuring that the object moved straight on the ramp and that the sensor was "clicking rapidly" meaning it was collecting data. He then showed the results by sharing the screen.



He asked the students to explain what was going on at the end of his graph. One of the students responded that the car crashed at the end creating the spiky data at the end of a curve. He noted that everything stopped making reference to the velocity time graph being at zero the distance traveled being the distance to the end of the ramp. He explained that the first two seconds of his experiment was a nice graph and showed what was going on with the experiment. He then demonstrated on his screen how to save the data using the logger pro software - using save as so the students could name their data file. He then explained how to get another collection of data by going up to the menu "Data" and how to clear data for the second run.

During this time he was troubleshooting several students who are having difficulty and asking questions about their graphs.

Figure 13. Field notes from Norman's lesson introduction. The upper graph is for distance-time motion, while the lower graph depicts velocity over time. Norman uses the graph to explain motion to the students.

The field notes show that Norman used the graph shared in Brightspace, visible to all students, to connect the motion phenomenon with the observed graphical output (noting that when the car stopped, the velocity-time graph was at zero). This supports the students' understanding of kinematics by connecting motion observed with displayed graphical results.

The Outcome

Early in the study phase, Norman wondered, "I don't know whether we can actually get a graph that's going to be reasonable." The students at the remote sites successfully used their Toolbox instruments to collect the motion data and produced graphical representations on a distance-time graph. Viewing these results and connecting their sensory experience of motion with graphical outputs is one of the desired outcomes of LS group activity (Figure 4). The students of the four remote classes used computers (instruments) to display mediating tools (psychological tools) such as the acceleration inquiry document (instructions), the Google Doc with hypermedia (training), and application sharing (graphs or signs). Their acceleration inquiry activity was completed in less than 50 minutes; in two time zones and 21 remote contexts, over 50 students independently collected the data they would later use to calculate instantaneous velocity and compare changes over time to demonstrate acceleration. Some students presented motion misconceptions in their predictions portion of the acceleration inquiry – the most common was a straight line to depict acceleration. These outcomes impacted future instruction using the data collected on their ramps with the school Toolbox instruments (Wells et al., 2022).

The LS Reflect Phase – Evaluation and Questioning Practice

Based on the success of Diane's students during the acceleration inquiry, a seemingly redundant hypermedia Google Doc question was asked, "So obviously the videos and the files worked?" Diane responded, "The videos, the files and then the fact that we did the run-through. Yeah. So, they had everything they needed." The psychological tools (the inquiry lab document, Google Doc with hypermedia) and synchronous practice sessions combined to move the students through the zone of proximal development and produced the *Outcome*. However, Diane noted that without training and practice, her second class did not fare as well, “If you watched my second class, they were a lot bumpier …we had to troubleshoot a lot more because half the class at the time was at home when we did the first lab [practice].” This suggests the psychological tools alone could not bring some students through the zone of proximal development to complete their data collection to achieve the outcome of other students who received complete training.

Student Outcomes and Balanced Remote Support

The students demonstrated skills during their independent remote construction of the inclined plane apparatus and use of Toolbox - a satisfying outcome. The knowledgeable other, a teacher who previously used strict confirmation inquiry in the same context, commented, “I was really happy with the balance struck between guidance and inquiry... I have always struggled with it from my very earliest days of teaching right up until this very moment.” The knowledgeable other offered an anecdote, a question from former students, “Sir, we don't know what we're doing wrong. We've done this lab over and over again and we still keep getting zero percent discrepancy. What are we doing wrong?” The knowledgeable other emphatically stated:

> Let that sink in. So, the students were precisely following our instructions, getting perfect responses and still obviously didn't have a clue what they were doing. And that was on us, that was not on them, that was totally on us.

The knowledgeable other acknowledged the buttressing effect of the psychological tools developed for the students during the LS, “I was smiling when I was looking at your instructions, because you nailed it right…you gave them the right amount of information, but not too much and certainly not too little. Nailed it.” These positive comments acknowledge the importance of contradictions that forced the development of the psychological tools (Table 2).

Table 2.

The levels of contradictions of the second-generation activity system for developing the remote research lesson.

Phase	Contradiction Level	Description
Professional learning	Level One – within subjects	Time dilemma - time concerns for developing and conducting the remote science inquiry lesson related to technology, training, and logistics.
Study	Level One – within subject node	Dilemma for unit of study – Motion was almost completed but Ecology would not use the desired graph producing Toolbox instruments.
Study	Level Two – between subject and community	The “one teacher” contradiction arose due to the unknown skill set of the teacher assigned to supervise the remote students.
Study	Level One - within subject node	The Toolbox double bind – the teachers want to use the Toolbox but that requires time for training the teachers and students or resorting to the practice of “giving” the students data.
Plan	Level Two - contradiction between community node and subject node	Commitment to student training, the discovery of multiple interfaces in toolboxes at school sites (Community). This required changes in activity and Subject tool building of psychological tools - the Lab Document and Google Doc with Hypermedia.
Plan	Level Two – contradiction between the subject and community	Student feedback contradiction for the Subject. Norman was initially not interested in student predictions (hypothesis) while Diane and Paddy argued they were important for engagement and revealing students’ kinematic thinking.
Teach	Level Two – contradiction between subject, object, and community	Off-site students proxy teaching operation - reduced the Subject’s ability to facilitate remote school sites as off-site students lacked access to equipment. Teachers supported remote lab data collection by acting as a proxy for at home students while offering school site students formative assessment and troubleshooting – splitting teaching operations.

Reflection	Level One – contradiction for the Subject	Teachers were surprised by students lack success in predicting graph shapes and lab report outcomes leading to questions about the level of inquiry.

The Proxy Teaching Operation and Other Object-Driven Contradictions.

Although it seemed harmless at the time, the teachers acting as proxies for students who did not have equipment split the teachers' attention between the on-site and off-site students. The teachers were highly motivated to have students collect data and use data that was personal, "their data," according to Diane. In retrospect, however, an observable dilemma was created as teachers were actively troubleshooting student groups in distance-education schools while supporting the data collection for students not on-site. This dilemma is based on the collective goal for students to collect personal data. However, the proxy data collection with a small group of students limited teachers from supplying timely feedback to other students.

If one considers the importance of addressing the misconceptions, supporting students without equipment interfered with the formative assessments during the lab activity. The teachers did not have the time to address all the misconceptions that presented themselves during the *predict* phase of the remote inquiry; this dilemma manifested a level-two contradiction (Engeström, 2015). Like the object, contradictions changed over the LS cycle resulting in new contradictions (Table 2).

Contradictions and Time

Time was a variable that contributed to the activity system's contradictions from the first professional development meeting until the lesson was completed (Table 2). Time was a consideration during all meetings and was managed as a part of it the division of labour. The "one teacher" of each remote school with unknown qualifications conflicted with the "Toolbox double bind" that resulted from teachers' desire to use the Toolbox. Addressing the precondition of the "one teacher" required time; the time for training and developing psychological tools to bring students through the zone of proximal development to use tools independently. These contradictions occurred during the study phase, while entry into the plan phase started with the actual specifics to be addressed in the lesson. As the teachers worked together, they moved through the zone of proximal development that permitted the movement to the next phase of LS (conducting operations such as verifying the student software). As the lesson context defined, a new zone of proximal development with new contradictions arose, requiring action and operations. The Toolbox training contradiction required tool-building actions to achieve a desired goal and operations, such as developing the acceleration inquiry doc or the Google doc with hypermedia to meet the predicted conditions for the remote students. Before changing to the teach phase of LS, the operations of tool building and the practice session with students collectively addressed the Toolbox training contradiction (Table 2). Once again, the teachers collectively moved through the zone of proximal development as they addressed the contradictions within the context of lesson development that considered potential student outcomes or difficulties. The object drove their activity, actions, and operations (Leont've, 1981).

The Prediction Confliction

The teach phase of the LS introduced teachers to the students' misconceptions of motion and graph shape (Figure 10). The teachers were perplexed that the confirmation inquiry versus guided inquiry did not produce better predictions; this problem was examined in detail by Wells et al. (2022). There is insufficient student data to resolve the reasons for these differences. However, I taught this unit yearly for over ten years and was not surprised by this contradiction – I predicted it. My reasoning is a lack of experience. "Given that students may have little experience with motion on an inclined plane and acceleration, it is not surprising that most of their predictions were incorrect or incomplete." (Wells et al., 2022, p. 30). Graphing motion presents a significant challenge for students, regardless of the "provided scaffolding for students to understand the results, such as reminding them to identify errors and to clarify which parts of the graph provided good data" (Wells et al., 2022, p. 24). A student's experience is the major factor in learning to graph and predict graph shapes. "Graphs that show real and predicted motion of an object over time help students cognitively link motion with how a graph looks" (p. 31), and the pandemic limited the student instruction using the Toolbox. Students within my classes prior to the pandemic had two distinct advantages – weekly activity using similar tools and student lab groups that met face-to-face with teachers to explain their predictions, results and identify misconceptions (Wells & Ricketts, under review).

In my experience, numerous scaffolded experiences reduced student graphing issues by the end of the Motion Unit; however, the students in my classes, like their remote counterparts, made many incorrect predictions for constant and changing motion (acceleration). These student misconceptions are valuable sources of learning (Posner et al., 1982), as are the teacher contradictions within this investigation.

Expansive Learning

This activity theory analysis reveals that contradictions were encountered in professional learning and all phases of LS (Table 2). If, during developmental work, an innovation occurs that changes the object and related activity where new actions result or are required, then expansive learning has occurred (Engstrom, 2001). By definition, expansive learning activity is unique and "is an activity-producing activity" (Engeström, 1987, p. 125). Further, Engeström and Sannino (2010) state, "Initially individuals begin to question the existing order and logic of their activity. As more actors join in, a collaborative analysis and modeling of the zone of proximal development are initiated and carried out." (p. 6). These characteristics are present within the LS of this investigation; however, was this LS for remote science inquiry instruction expansive learning?

Lesson study, with its concrete structure (Lewis, 2006), is arguably a form of intervention; however, it is not a Change Laboratory designed to produce expansive learning (Augustsson, 2021; Engeström, 2001; Engeström et al., 2013). According to Engeström et al. (2013), "A Change Laboratory is typically conducted in an activity system that is facing a major transformation. This is often a relatively independent pilot unit in a large organization." (p. 82). Further, the Change Laboratory is designed to address the seven expansive learning actions: 1. Questioning, 2. Analysis, 3. Modelling the new solution, 4. Examining and testing the new model, 5. Implementation of the new model, 6. Reflecting on the process, 7. Consolidating and generalizing the new practice (Figure 6, Engeström, 2001). The present LS completed this cycle with activity similar to that of the expansive learning cycle (Figure 6); however, Table 3 compares the actions and operations of the Change Laboratory with the phases of LS and prior professional learning conducted by the remote teachers and the knowledgeable other of this investigation.

Table 3.

Comparing actions and operations of the expansive learning cycle with the actions and operations of LS.

Stage of Expansive Learning (Engeström, 2001)	Professional Learning and LS phases (Lewis & Hurd, 2011) with activity, actions, and operations (Engeström, 1987; Leont've, 1978)
Questioning – Need state	Pre-lesson study identification of technology needs - actions and operations
Analysis – Double bind or contradictions	Study – Examining curriculum outcomes for the unit of study and the Toolbox double bind and software operation
Modelling the new solution – Breakthrough	Plan – Planning the lesson activity with solving instructional problems actions with tool building operations
Examining in testing the model – Adjustment and enrichment	Plan –Practice Activity - sharing the tools to the students and testing solutions during the Toolbox practice action with teaching operations
Implementing a new model	Teach - Enactment of Object Action - remote science inquiry instruction action – the teaching is the action with many instructional operations such as student feedback on experimental results.
Reflecting on the process	Post-Lesson Reflection Action - The examination of the object as presented, with operations such as minor adjustments to the presentation and questioning predictions.
Consolidating and generalizing the new practice	Collective Reflection Action – Discourse operations with acceptance of the tool use and practice operations for future lessons.

Within Table 3, there are two distinct super-order stages of activity, overlaying the professional learning and the phase of LS, that is not visible. Namely, the gradual formation of the germ cell ends with the decision to conduct a remote inquiry for acceleration and the expansion of the object through the zone of proximal development during Plan, Teach, and Reflect resulting from activity, actions, and operations (Figure 14).

The germ cell was formed in response to perceived conditions that could be addressed with operations - although contradictions and a double bind (manifestation of a contradiction) remained unresolved (Figure 14). Once formed, after the choice unit dilemma was resolved, contradictions evolved based upon the choice of action, such as the decision to train the students with a Google Doc with hypermedia and conduct practice.

Each step in the phase of LS was made possible by the prescribed action of the LS cycle (Figure 1) and supported the collective action through the zone of proximal development of the object. Tool production was an important operational aspect of the expansion of the object; without the previous phases of LS to formally identify the unit of study, it may have been more challenging to realize the need for tools to support the students’ remote inquiry. During the action of tool building, operations produced the Google Doc with hypermedia and Acceleration Inquiry Doc.

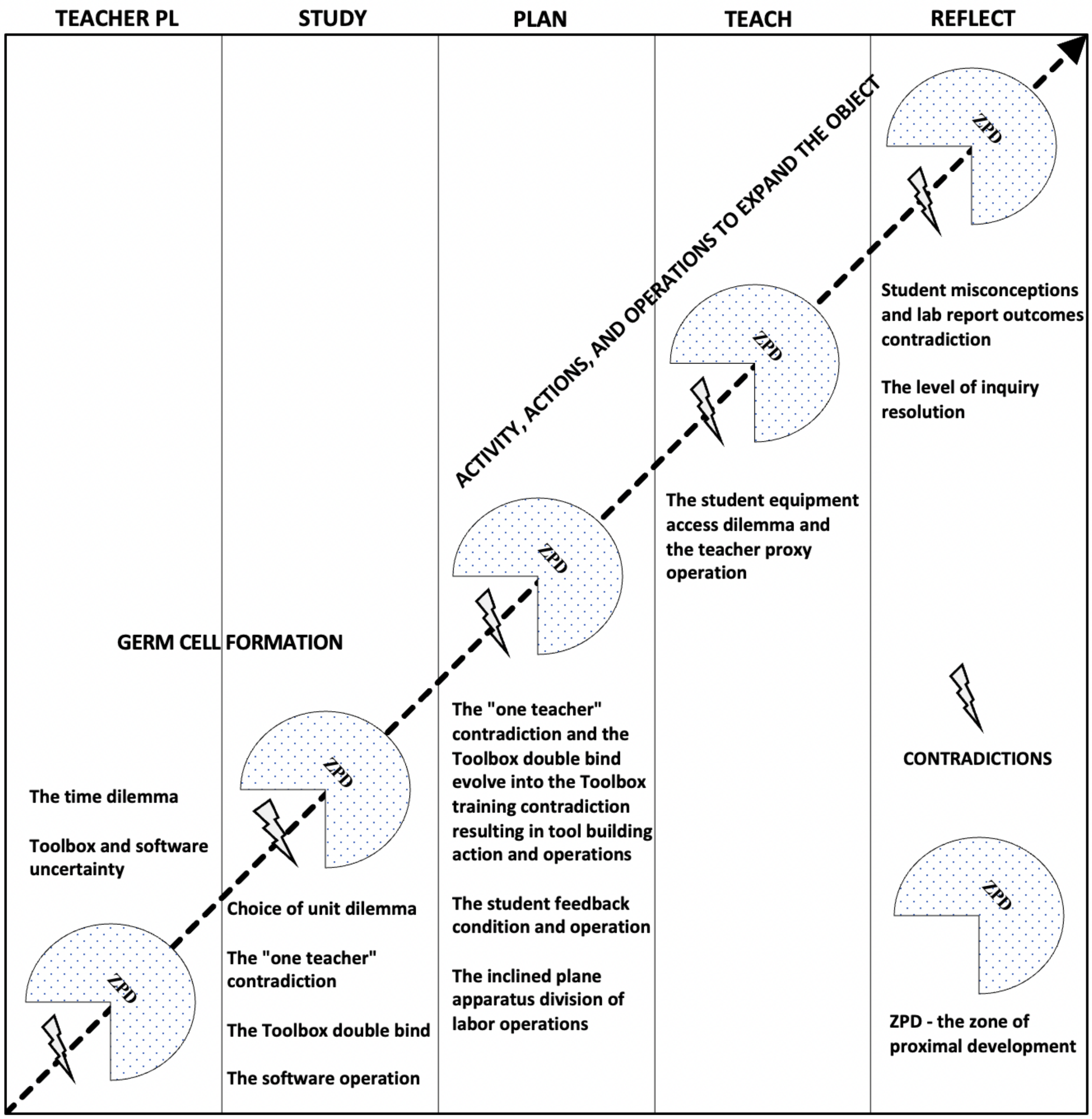


Figure 14. The progressive expansion of the research lesson or object, during the phases of lesson study and prior professional development (TEACHER PL).

Lesson Study is a Psychological Tool That May Support Expansive Learning

Lesson study has a 100-year history (Seleznyov, 2018) as a process that guides practitioners through logical steps that build towards improving the research lesson (Lewis &

Hurd, 2008; Stigler & Hiebert, 2009). The prescribed goals of each phase LS (Figure 1) acted as a scaffolding for the LS group, a psychological tool of a step-by-step process with goals requiring actions that set conditions for operations to develop their remote research lesson – supporting development of the ZPD seen in Figure 14. The data collected during teacher professional development introduced the teachers to LS protocols; this engagement also produced the first contradiction (Table 2). During this phase, there was evidence that the teachers wanted to proceed as quickly as possible to their goal of a student inquiry that used data collection devices. Initially, there was evidence that time was a considerable stress to the teachers. Norman was concerned about the time for lesson development and appeared to have a product in mind; Diane also had a product in mind, but she had no preference for a unit. Neither of the two study teachers or research participants had participated in a collaborative form of professional learning that developed a lesson. However, the LS phases provided a structure that slowed the process and allowed for addressing important terms required for the product research lesson. For example, the study phase of LS requires teachers to examine the curriculum and decide upon a unit of study – resolving the unit of study contradiction required careful negotiations between the LS teachers. Due to the experience of the teachers, the conversations linked components of the course curriculum to the development of a lesson that focused on instruction for students' skills and knowledge in the remote teaching context. Diane noted during a group reflection, "the product is getting better and better... So, I think it all starts to come together because the focus is on the kids. How do we teach better to get to those kids." The lesson improved over time due to the foresight of the teachers and the collaborative work that accumulated the knowledge required to complete the image of the object and produced an outcome that continued the expansive learning into the reflection phase of lesson study. The lesson changed very little after the reflection discussions; however, the reflective discourse confirmed what functioned and should be retained for future instruction – an example of how the LS process contributed to teacher learning as PCK (Wells et al., 2023).

Implications

This activity theory analysis of remote LS for remote science inquiry instruction (Wells et al., 2022) reveals teachers' expansive learning, nuanced features of remote LS, and the complicated process of preparing for a remote science inquiry. Aside from the participants, the expansive learning of this remote study required three crucial ingredients: time, instruments, and mediation with psychological tools.

Time - Contradiction Versus Motivation

From the start of the LS intervention, time was a factor in existential decisions for developing the research lesson. Diane and Norman opposed "printing the data for the students," yet, it was proposed as an undesirable alternative if the production of tools and practice failed to support the students' independent collection of motion data. Time factored in the training contradiction and several operations – such as the division of labor for the inclined plane apparatus (Figure 14). Paradoxically, the proxy teaching for students off-site sacrificed the quality of student feedback during the lesson to include off-site students; the feedback expended time in classes that followed.

Time and Contradictions in other Activity Theory Studies

Lewin et al. (2018) found that a digital tool kit designed for practitioners to support teachers' digital pedagogy using learning design for lesson planning created time-related contradictions. The tools "such as maturity modeling, were noted to be particularly time-consuming for teachers" (p. 1139) and slowed the development of the scenarios and learning activities. Reports from partner countries stated, "Everyone has time constraints. It is difficult to find an occasion when you can bring together a school head, ICT coordinators in several teachers." (p. 1139). Lee and Tan (2020) reported that a professional learning team group of nine elementary school teachers, who conducted two cycles of LS and found that time constraints led to disturbances in teacher learning due to the "focus on logistical issues, rushed discussions, and struggles with notetaking" (p.9). Bevins et al. (2019) interviewed 10 English high school science teachers who valued inquiry to determine impediments to conducting inquiry-based instruction, and the most cited teacher issue was "lack of time" (p. 542). Like the high school teachers of the present study, the teachers studied by Bevins teach a curriculum with a significant content focus. The result is a "concern for complete coverage of the necessary curriculum content required for potential examination success." (p. 542). Another time-saving alternative for coverage is using teacher-centred instruction to try to reach the same outcome as the other form of instruction. DeBeer (2019) reported that a teacher used this strategy to cover material versus a student's hands-on work with a DNA barcoding lab. Four South African physical sciences teachers conducted LS, and the analysis by Ogegbo et al. (2019) found similar experiences - time was challenging for meetings and LS participation.

A significant difference was institutional support: CDLI strongly supports teacher LS and schedules teacher collaboration, while Ogegbo et al. (2019) report shortages of instructional materials and logistical support issues. Further, two teachers reported problems with a “loaded curriculum” and that “learners struggle with the pace of physical sciences” (p. 6). These community differences impact how the LS group would develop a research lesson as the object of the subject’s activity.

Covering content as a response to testing pressure fuels contradictions resulting in the “time contradiction” reported in the literature. Time factored in several contradictions of this study - in a pragmatic approach is to cover and curriculum, chalk and talk or lectures are sometimes required to allow students to conduct hands-on activities. The pressures related to time for science teachers reportedly influence the decision to use inquiry instruction (Harris & Rooks, 2010; Loyens & Gijbels, 2008). Teaching via inquiry has more recognizable benefits for the students - thus, the regrettable choice to lecture resulting from time pressure is an example of a time paradox (Zimbardo & Boyd, 2008).

Instruments

The instruments of this investigation were the vessel for the mediating psychological tools such as Brightspace, application sharing, graphing applications, and the acceleration inquiry doc; without instruments, the lesson could not proceed. The presence of instruments, even those that needed to be replaced, required operations to set the conditions necessary for conducting the remote inquiry. For example, if probes were missing, they were replenished through CDLI technical staff operations. However, the instrument paradox was how they featured in the majority of the contradictions throughout the LS (Figure 14).

Instruments Used in CDLI Past and Present

In 2009, Murphy and Rodriguez-Manzanares published a study of expansive learning with 13 e-teachers from CDLI. Within the context of this study, specifically CDLI and remote site schools, changes in instruments impacted science instruction. Each distance education teacher had changed their context when hired by CDLI, from working in a brick-and-mortar school where the “physical co-presence formed the basis of interaction and communication.” (p. 2). As e-teachers working online with remote decentralized classrooms, “communication and interaction were mediated almost entirely by text and voice” (p. 2). The current CDLI teacher practices for class-based communication include video, voice and text. Web 3.0 has significantly improved over the Web 1.0 of the teachers Murphy and Manzanares (2009) studied; however, many students do not have webcams due to bandwidth issues. Most students have smartphones with a camera and email – instruments allowing them to text and email pictures of their apparatus and results – a technological leap exploited by teachers of the present investigation by requesting that students send them images via email from their smartphones.

When teaching with information and communications technology (ICT) tools, Plakitski (2013) warns, “when we use bold ICTs, we can lose sight of specific goals of teaching and learning. Any learner must at least be aware of the objectives of the activity.” (p. 74). Further, “Only when tools mediate subject-object authentic interaction into a meaningful activities system can meaningful learning occur” (p. 73-74). In the remote classes of this study, the ICT tools made class interactions possible, while the mediating psychological tools made them meaningful. It is difficult to deal with significant contradictions during the developmental process, “Seeing contradiction as an inconsistency or competition between separate forces or priorities corresponds to the general mechanistic tendency to replace intersystematic contradiction with outer, external oppositions" (Engeström & Sannino, 2012, p. 371). This study's outer, external oppositions to the LS were mediated with psychological tools.

Mediating psychological tools

Psychological tools are artificial formations and, by nature, social – such as the Google doc with hypermedia used by student lab groups to learn how to set up apparatus and collect data. Examples of psychological tools include "language; various system for counting; mnemonic devices; algebraic symbol systems; works of art; writing; schemes, diagrams, maps, and mechanical drawings; all sorts of conventional signs; etc" (Vygotsky, 1981, p. 137). Computers and data collection probes were not mainstream teaching devices during Vygotsky's experimental work. However, within this Google doc with hypermedia are found many of the psychological tools cited above - language, counting systems, diagrams, and other conventional signs.

Teacher-created mediating tools

How did the acceleration inquiry doc and Google doc with hypermedia impact the students? Within the present study, these tools supported students' development of data collection skills as they learned to use the probes and interface. In this regard, the hypermedia Google Doc was a cognitive tool. However, the role of hypermedia is complicated, with mental and metacognitive processes and regulatory processes (Azevedo et al., 2010). Chambel et al. (2006) posit, "In some learning situations, videos or animations are not only a desirable but an important prerequisite for successful learning to take place." (p. 32). The acceleration inquiry document and hypermedia support were the visualizations of a dynamic process. Chambel et al.

report, “audiovisual presentation formats facilitate the comprehension and transfer of knowledge, especially in those domains where dynamic processes and concrete objects or complex systems need to be observable for a proper understanding of the topic” (2006, p. 32).

According to Roth et al. (2009), “Tool mediation not only captures the relationship between subject and object but is also closely associated with other activity moments such as community and division of labor” (p. 145). In shaping the object (research lesson) during LS, the LS group was forced to consider the students, how they may function in lab groups, and any restrictions they may face in their remote school context (Wells et al., 2022).

In my face-to-face experience, it is initially challenging to instruct students how to use data collection, interfaces, and probes (Wells & Ricketts, 2023). The development of this psychological tool followed the LS cycle, which acted as a form of user-centred design for an interactive artefact (Kaptelinin & Bannon, 2012). Predicting the students’ needs and difficulties based on the remote contexts and their troubleshooting needs (Wells et al., 2022) was essential to the user-centred design and success of the tool. This parallels the user-centred design process seen in Figure 15.

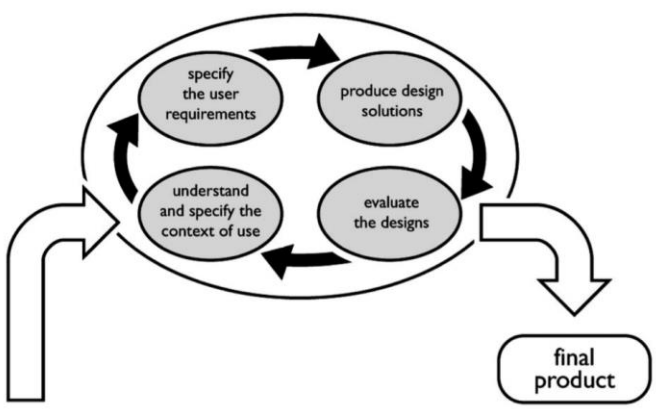


Figure 15. The user-centred design process (Kaptelinin & Bannon, 2012)

Lesson study – a psychological tool.

Technology-dependent remote LS is not recent (see reviews by Huang et al., 2021a; Huang et al., 2023) and has resulted in expansive learning (Huang et al., 2021b). A caveat of the plan stage is considering student thinking and problems during the lesson (Lewis et al., 2006a; Lewis & Hurd, 2011) and predicting outcomes. Guskey (2014) suggested that successful high-quality professional learning requires that "we must plan backward, beginning with student learning outcomes we want to affect" (p. 16). To ensure or improve the odds of success, LS teachers faced contradictions that required developing mediating tools (Figure 14) that were produced and tested before the lesson. The teachers adopted this strategy because they were conducting LS teacher research. The plan phase of the cycle requires teachers to try the lesson task and anticipate student thinking (Figure 1). Thus, the LS cycle is the mediating psychological tool for teachers' professional learning.

The e-teachers of our investigation changed, as did their CDLI predecessors (Murphy & Rodriguez-Manzanares, 2009), due to expansive learning caused by contradictions related to the instruction. For the teachers, the object was focused on e-teaching, where past practices were questioned, and new forms of activity developed. The main parallel was that the teachers, then and now, were the former teachers considered the source of knowledge while the teachers of this investigation acted as lesson facilitators. Within CDLI there are networks where teachers passed their experience and skills. For example, any self-selected teacher groups work for mutual support or groups formed by the administration would be termed PODs (pers. com. Nancy Manderville, CDLI Program Specialist).

Before 2009, due to the bandwidth issues and CDLI teacher practices, most of the class-based communication remained to a lesser degree, voice and text. Web 3.0 has significantly improved over Web 1.0 of the teachers studied by Murphy and Manzanares (2009). For example, texting in a Brightspace group chat was a private or public form for asking questions and making jokes for students of this study. These tools were not mentioned by Murphy and Rodriguez Manzanares (2009).

Student mediating tools - predictions

McPherson and Pearce (2022) found that remote science teaching made "it difficult to gauge student understanding when their cameras were turned off. Without visual feedback, teachers found it difficult to assess students' understanding." Student feedback is essential for teacher learning (Carlson et al., 2019) as it is a formative assessment for students (Black, 2015). The COVID-19 pandemic, as a runaway object (Engeström, 2016), created a context that limited both teacher and student social sensory connection, demanding that teachers adopt new practices (McPherson & Pierce, 2022; Wells et al., 2022). This change, caused by a runaway object, was paradoxical as for many teachers and called for is nothing less than a change in how they perceive and strive to implement their role as teachers (Black, 2015, p. 171).

Murphy and Rodriquez Manzanares captured one of the essential differences between face-to-face classrooms and the e-teaching context. In the online classroom, the lack of physical co-presence as a mediating tool made it more difficult to spontaneously interact with students because, as one individual commented, "You don't get to see the reactions, you don't get to see the frowns or smiles, you don't get to take visual cues from your environment… you are not getting the body language." (p. 10). This sensory deprivation was a concern of the LS group that was overcome using the POE strategy (Wells et al., 2022), which requires students to predict the outcome of the lesson. While only ten students made public predictions, all completed a drawing of their expected graph shape for motion on an inclined plane. The e-teachers of Murphy and Rodriquez Manzanares's study experienced similar difficulties with getting students to comment using voice communication; they preferred text-based messaging. However, as with the teachers in the study, “Some teachers referred to taking advantage of private communication feature of instant messaging for one-on-one support outside of class or for feedback and synchronous classes” (p. 10).

Conclusion

After the germ cell formation, the research lesson (object) expanded ontogenetically as the teachers addressed the conditions producing contradictions that reset goals, resulting in actions and operations (Leont’ve, 1981) that included the construction of psychological tools. Most of the contradictions of this remote LS were driven by the object (research lesson) and produced a perceived need state in the subject teachers; the need state evolved as the teachers moved through the zone of proximal development while maintaining their image of the object. Motivated activity toward the research lesson object of the second-generation activity system demonstrated the teachers’ actions and operations to produce the necessary psychological tools to support independent student science inquiry at remote sites. The mediating tools developed in response the perceived student need-state taught the students how to physically use the instruments to conduct an independent investigation at the remote sites. These tools are an example of expansive learning as they transformed the subject of teacher learning (Engeström, 2016). Using the mediating tools (psychological tools), the students proceeded through the zone of proximal development for instrument use and, during the lesson, produced their own signs or psychological tools (outcomes). The acceleration inquiry document required student predictions (signs for the teachers and students) that conflicted with the inclined plane experiment graphical results. During the LS, the teachers experienced expansive learning as they constructed the research lesson (object) with the tools that and successfully developed strategies to conduct remote science inquiry instruction.

Limitations

Three teachers (including the author) were the study participants and the primary data source. The group has specific qualifications and cultural connections with science teaching and learning (Table 1). Therefore, the results of this study are not broadly generalizable to teaching in general; however, readers may find phenomena described within this case study that apply to their context.

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Chapter 5 - Summary

> It's ownership. It's authenticity. If it's not yours, you're not going to remember. It is not going to mean anything . . . So, once the kids get that in their hands and that becomes their experience, that was their ball, that was their ramp, that was their graph. We talked this morning about how we analyzed the graph of the big blue ball. That big blue ball meant something to those kids. That graph all of a sudden became theirs . . . and that's what enriches the activity. So, the more you can get the kids engaged and it becomes theirs, then that's where you're learning, and your deeper learning starts.
>
> (Diane, distance education science teacher)

The inclined plane lab was the context for student learning. Diane's passionate commentary reveals the motive for developing the acceleration inquiry document, constructing a Google Doc with hypermedia, and conducting a practice activity – a vision to conduct a student-centred, meaningful remote science inquiry. Their work towards the research lesson inclined plane lab was shaped by contextual forces, some known, and others emerged as they followed the steps of lesson study (LS). The common thread of the manuscripts that constitute this thesis is LS and the four unique phases - study, plan, teach, and reflect (Lewis & Hurd, 2011). The result is teacher learning as PCK (Carlson et al., 2019) during LS in Chapter 3. Chapter 4 focuses on the development of a remote science inquiry that employs the predict-observe-explain metacognitive instructional strategy (Gunstone & Mitchell, 2005). Finally, in Chapter 5, CHAT analysis (Engeström, 1987) reveals expansive teacher learning and the mediation of learning with psychological tools during the development of the research lesson.

Arguably, the LS phase structure provided guidance during the remote lesson study that contributed to the remote lesson's development. Initially, LS's structure and required meetings created trepidation, evidenced by Norman's statement, "We don't have a whole lot of time." However, the LS group completed the task on time while demonstrating the importance of student outcomes – particularly for teacher ePCK (Carlson et al., 2019).

Lesson Study ePCK by Phase

The teachers' knowledge gains during the LS plan were notable. Diane and Norman gained curriculum knowledge, assessment knowledge, instruction knowledge, student needs, and content knowledge (Table 1).

Table 1.

New ePCK by phase of LS (KC-knowledge of curriculum, KA-assessment knowledge, KS-knowledge of students, CK-content knowledge, F-filters, Amp-amplifiers, RIA-Reflection in Action, ROA-Reflection on Action).

Teacher	Study - ROA	Plan- ROA	Teach and Re-teach - RIA	Reflect - ROA
Diane	KC Amp-decision making	KC KA-formative assessment KI-practice (RIA) KS-needs, learning difficulties, & motivation CK-motion	KA- formative assessment KI-conducting RSII KS- motivation, misconceptions, & needs	KS-misconceptions & needs
Norman	KC Amp-decision making	KC KA-formative assessment KI-practice (RIA) KS-needs, learning difficulties, & motivation	KA-formative assessment KI-conducting RSII KS- motivation, misconceptions, & needs	KS-misconceptions & needs

However, during the LS teach phase, the teachers' used ePCK and reflection in action to teach a new lesson developed as they reflected on action during the study and plan phases. The lesson was, therefore, untested. The short time the lesson was in the wild is synonymous with Natural Selection, as some of the enacted ideas from the plan phase would be retained for further use; recruited into the teachers' pPCK. Strategies that did not survive selection were cast aside or adapted. The POE formative assessment strategy for student misconceptions and tools for asynchronous training for conducting RSII survived the final reflection on action (Table 1). A reflection in action adaptation for the lack of remote site cameras was student phone images sent to teachers via Gmail. The decision to retain a new strategy or create an adaptation was not based solely on the quality of an idea. If student feedback and outcomes during the teach phase of LS confirmed the instructional value of ePCK, such as tool use of training, these elements were retained for recruitment into a teacher's pPCK.

RSII and Planned Student Noticing

RSII is a newly reported form of science instruction that has been in use by CDLI in several high school science courses. RSII uses technology, physical apparatus, and synchronous remote teacher guidance to support a hands-on remote inquiry. Although remote and virtual labs are sometimes suggested as an alternative to hands-on laboratories (Heradio et al., 2016), virtual manipulatives differ from physical lab equipment (Olympiou & Zacharia, 2012).

The use of probes, regardless of the form of inquiry, benefits the student, particularly in skills such as data collection, data analysis, and graphing (McDermott et al., 1987). The students used Vernier® probes and interfaces during synchronous instruction with teacher support in Brightspace. The predict–observe–explain (POE) strategy (White & Gunstone, 1992) elicited samples of student thinking that fostered teacher noticing of student misconceptions for graph shape and the type of motion.

During the remote inclined plane inquiry, motion was simultaneously graphed as an object accelerated down the plane. The teachers provided feedback via application sharing, chat, and voice comments in Brightspace. This lesson enactment demonstrated that students could successfully conduct an inquiry when provided with appropriate asynchronous resources and online synchronous support. Finally, this investigation reinforces the importance of predictions in science instruction as an essential part of finding misconceptions and addressing them as the students construct meaning during the inquiry process.

CHAT Contradictions, Psychological Tools, Mediation, and Expansion

The CHAT analysis provided the lens that revealed the most compelling teacher and student learning during LS. The second-generation activity system nodes of community, division of labour, and rules (Engeström, 1987) illuminated how the social variables impacted the development of the research lesson. The analysis focused on the changes in the research lesson (object), or lesson ontogeny, during each unique phase of LS (Figure 2). Before the object could expand, the teachers used information on perceived student conditions to set goals for action. Contradictions arose within nodes, or between nodes, as detected conditions interfered with the goal of the LS. For example, the study phase negotiations supported the formation of the lesson germ cell; however, dilemmas and double binds, manifestations of contradictions resulting from the identification of the object, pushed the teachers to build tools. The resulting teachers' double bind was, use valuable time to build tools to support the students or resort to the undesirable practice of providing students with data and deprive the students of conducting a technological inquiry (the Toolbox double bind, Figure 1).

The teachers' actions were in the taxonomy of Leont've (1981) hierarchical levels of activity. The activity system was driven by the motive to realize the object (the research lesson). The goal-orientated actions, such as tool building to support the remote students, responded to the conditions created by the manifestations of contradictions. The response to conditions was operations such as building the acceleration inquiry doc or the Google Doc with hypermedia. However, until the teach phase, it was unknown whether the operations would satisfy the goal of action and Diane's above motive for activity (Leont've, 1981).

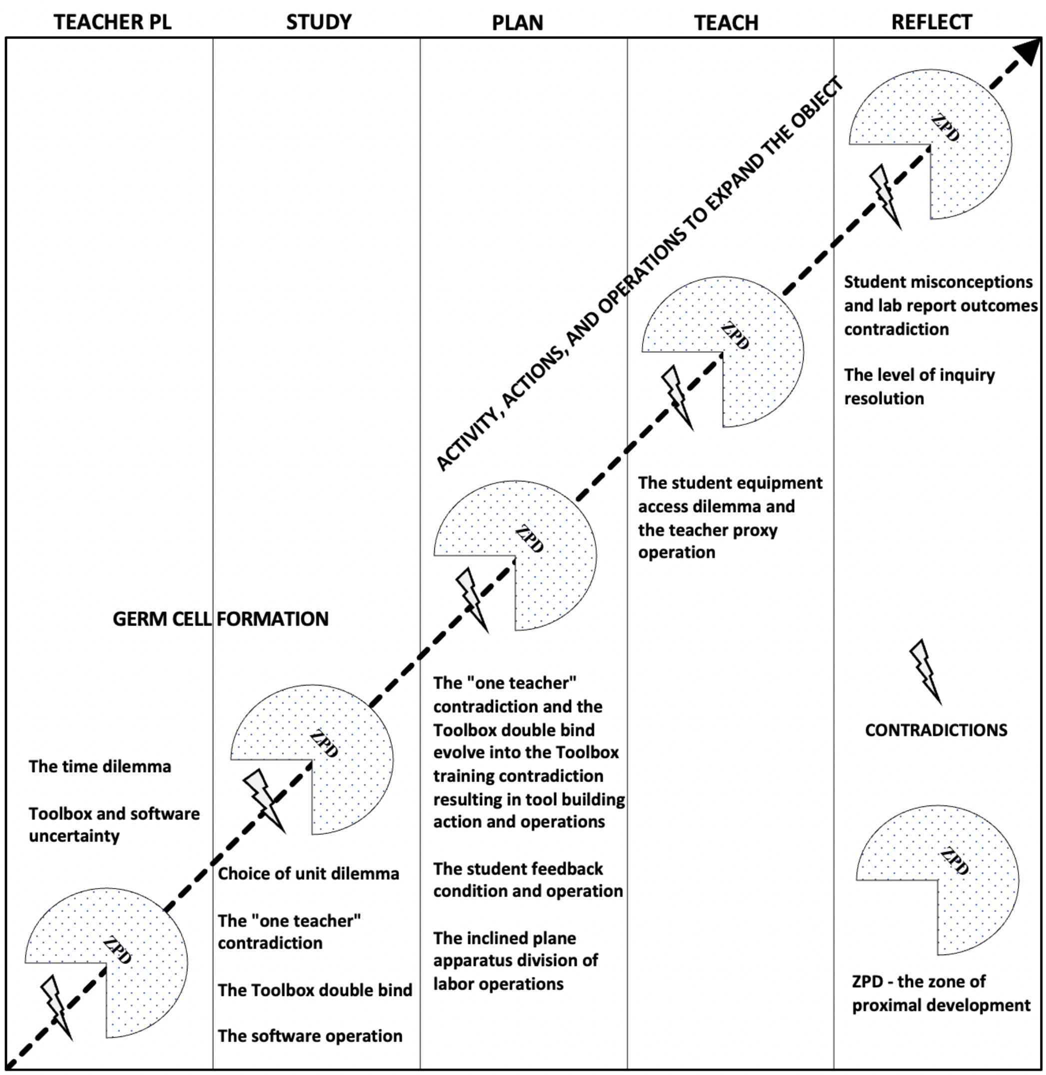

Figure 1. The expansion of the object during the phases of LS.

Teach: The Test of the Study and Plan Phases of LS

The teach phase was short and intense, a crucible determining the success of the 12 weeks of actions and operations during Study and Plan. How would the invested time and forethought abide within the instruction trials in multiple remote contexts? Would the lesson work? The LS cycle mirrors the Refined Consensus Model "Plan-Teach-Reflect" connected with pedagogical reasoning for teacher knowledge (Carlson et al., 2019). Further, there is reflection in action within pedagogical reasoning and reflection on action – the act of teaching uses reflection in action. While in action, the teachers responded to a contradiction that required proxy teaching operations (Figure 1). This engaged teachers' ePCK for decisions during instruction and students' knowledge to achieve the lesson action's goal (Leont've, 1981). During the lesson, there was little time to respond to the perceived student engagement with the lesson. Lortie (1976) termed these perceptions "psychic rewards" as feedback that created memories and within LS would be addressed during reflection.

While collectively reflecting on action in the reflect phase, I was privileged to be an insider and witness the power of LS as a psychological tool. For any LS critic who considers the phases overly prescriptive, I would counter that teachers entering social, professional learning have a greater chance of success when negotiations and consensus form the backbone of the proceeding phases. For example, the negotiations resulted in collective decisions about the unit of study, fair collaboration during the chosen lesson's planning, student data collection during the teaching session, and the positive and generative lesson assessment of the reflect phase. Ultimately the impact of the lesson on the students determined what components were helpful and what would be changed or discarded.

The LS egalitarian mechanisms helped teachers to test knowledge, develop ePCK and experience expansive learning (Engeström, 1987). The participants negotiated LS learning cycle, compartmentalizing aspects of lesson development, ensuring teacher engagement with examining curriculum, collectively planning a lesson, observing instruction, and data-driven collective reflection. In this regard, lesson study is a psychological tool that mediates teacher behaviour during the formation of the research lesson.

Finally, I posit that the mediation of operations for each phase of LS allows for the progressive growth of teacher knowledge during movement through the zone of proximal development (Vygotsky, 1978). In the study phase, the curriculum was reviewed, and the choice of the unit was negotiated, resulting in dilemmas and contradictions addressed with operations (Table 1). The development of the lesson considered student thinking and difficulties and lesson study. Thus, within the plan phase, the teachers' student-focused lesson negotiations moved through the zone of proximal development, constructing a research lesson by addressing student needs in actions and operations, such as psychological tool production to support remote students. During the crucible of instruction of Teach, the mediated students, mediated the teacher's predicted lesson activity with their operational responses to predictions and actions during the lesson. Student mediation moved the teachers through their zone of proximal development in the reflect phase. During the discussion of student misconceptions and lab report outcomes, they decided what was useful and impacted instruction; teaching strategies retained for future instruction.

The phases of lesson study progressively supported the lesson development and enactment. The final summation: A modern technical remote science inquiry was developed and enacted during a collaborative teacher endeavour - mediated by lesson study, a psychological tool that is over 100 years old.

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Appendices

Appendix 1 – COVID-19 District Announcement

Enter Search Term(s) Search

Newfoundland & Labrador English School District

"Be kind; everyone you meet is fighting a hard battle."
John Watson

ABOUT · STUDENTS & FAMILIES · SCHOOLS · PROGRAMS · CONTACT

COVID-19 (Coronavirus)
Information for School Communities

District Monitoring Ongoing Coronavirus Situation

THIS PAGE FOR REFERENCE PURPOSES ONLY - PLEASE SEE THE 2021 COVID PAGE HERE **FOR UPDATED INFORMATION**

The Newfoundland and Labrador English School District is in regular contact with the Department of Health and Community Service and relevant public health agencies as the situation surrounding COVID-19 (Novel Coronavirus) evolves. As with all matters of public health, the District will continue to take guidance from the Provincial Government and public health authorities in supporting our school communities.

Information on COVID-19 and its impact is available from the following resources:

- Updated Provincial Coronavirus Information - The Government of Newfoundland and Labrador (Health and Community Services)
- Updated Federal Coronavirus Information - The Government of Canada (Public Health Agency of Canada)
- Travel Advice and Advisories - The Government of Canada

PLEASE NOTE: As of Tuesday, March 17, the Government of Newfoundland and Labrador, in consultation with the District and the Chief Medical Officer of Health have suspended all in-school class instruction throughout District schools. This suspension will continue for an indefinite period, as part of province-wide efforts to reduce the risk of spreading the COVID-19 coronavirus. Further information can be found in the public releases shared below

The federal and provincial governments are advising that it is important for all travellers to:

- Self-isolate for 14 days after your return from travel outside of Canada (some provinces and territories may have specific recommendations for certain groups such as health care workers)
- Monitor your health for fever, cough or difficulty breathing
- Wash your hands often for 20 seconds and cover your mouth and nose with your arm when coughing or sneezing.

Health officials advise that the public health risks will continue to be reassessed based on the best available evidence as the situation evolves.

+ Information Shared with the Public

− Services for Students at Home

- **NL Guidance Services:** While in-school instruction is suspended, the District will continue to provide services and resources that assist students in managing their mental health and well-being. Students can call toll-free 1-833-772-0007 to be connected with a qualified, local School Counsellor OR fill out the Google Form in-take linked above.
- **Learning at Home: Good at Learning-Good at Life:** Learning at Home provides a list of resources for families to help support students during these challenging times. This resource is developed, maintained, and updated by District Programs staff and geared towards K-Grade9 families, with some resources for all grade levels.
  - **Well- Being** - Contains resources from trusted sources for individuals and families, as one of the most important things we can do at this time is to focus on our health and well-being.
  - **Literacy at Home** - Literacy is all around us; we use it everyday in many ways. Literacy skills continue to be developed throughout our entire lives. Trusted resources provided in this section are intended to foster a love of literacy at home.
  - **Math at Home** - Contains a number of resources to help guide students to independently continue to foster and support a passion for practical and real life learning opportunities.
  - **Passion for Learning** - During challenging times, the District encourages students to apply critical thinking to new situations that will positively impact our world. Let's re-imagine learning together!
- **Centre for Distance Learning and Innovation (CDLI):** CDLI offers an array of resources for several Grade 9 to Level 3 courses including learning resources, course review materials and various YouTube Instructional videos for a variety of courses.

Appendix 2 – Virtual research protocols

The Newfoundland and Labrador English School District (the District) is committed to the protection of privacy of students and families. Due to the Covid-19 pandemic, research approved by the District is to be conducted virtually. Researchers are to adhere to protocols outlined below.

- Research shall be conducted virtually via a Google Meet URL issued by the District, with privacy settings in place to ensure access by invitees only.
- Google Meet URLs shall not be shared with others other than those required to participate in the virtual meeting, presentation or classroom.
- Researchers shall not comment or share information on students or families participating in virtual meetings.
- Researchers shall ensure no other staff from their organization is able to view the virtual meeting, presentation, or class other than those identified to participate, and are required to ensure a secure space is used for the meeting with no other viewers in the room.
- Researchers shall not record or photograph virtual sessions, unless with written consent of the teacher, parent and or student (as per signed research consent form).

The NLESD required changes to the consent letters for teachers, science experts, and administrators. Subsequently, I review the details of the research protocols for online lessons study.

- Pre-research semi-structured interview via Google Meet.
- Full Day Professional Learning
- Regular meetings – Lesson study meetings were conducted following lesson study meeting protocols (Lewis & Hurd, p. 126-127).
- After 9 meetings, the first lesson presentation occured place followed by a group debrief of the lesson as per the lesson study protocol of Lewis & Hurd (2011).
- The lesson was presented within two weeks by the second teacher. This repeated lesson will include modifications suggested by the lesson study group following the first lesson debrief. The group will make observations of the repeated lesson and the student activities. A one-hour group debrief will follow on Google Meet and will include the teachers, administrator and myself.
- A final group debrief will occur when all lesson study activities have been completed. This will be a focus group session and may involve another school if enough teachers have been recruited.
- The data collection for teachers and administrators ends when they complete a final interview.

Science Experts

The expert science advisors involved in this research will join the Lesson Study Google Classroom where all instructions for the research process will be shared. Google Classroom is approved by the District and allows members to share documents, calendars, and is a forum for updates and questions. The Lesson Study Google Classroom will frame the following planned process for lesson study professional learning where participants will share the preparation of two lessons and present each lesson over a 12-16, week process.

Appendix 3 – ICEHR ethics clearance letter

MEMORIAL UNIVERSITY

Interdisciplinary Committee on
Ethics in Human Research (ICEHR)

St. John's, NL Canada A1C 5S7
Tel: 709 864-2561 icehr@mun.ca
www.mun.ca/research/ethics/humans/icehr

ICEHR Number:	**20201143-ED**
Approval Period:	December 16, 2019 – December 31, 2020
Funding Source:	Not Funded
Responsible Faculty:	Dr. Karen Goodnough Faculty of Education
Title of Project:	*High School Science Teachers' Professional Learning during Lesson Study for Student Inquiry*

December 16, 2019

Mr. Patrick Wells
Faculty of Education
Memorial University of Newfoundland

Dear Mr. Wells:

Thank you for your correspondence of December 1, 2019 addressing the issues raised by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) concerning the above-named research project. ICEHR has re-examined the proposal with the clarification and revisions submitted, and is satisfied that the concerns raised by the Committee have been adequately addressed. In accordance with the *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2)*, the project has been granted *full ethics clearance* to December 31, 2020. ICEHR approval applies to the ethical acceptability of the research, as per Article 6.3 of the *TCPS2*. Researchers are responsible for adherence to any other relevant University policies and/or funded or non-funded agreements that may be associated with the project.

Please complete the **ICEHR - Post-Approval Document Submission** form and upload the research approval documents from the Newfoundland and Labrador English School District.

The *TCPS2* requires that you submit an Annual Update to ICEHR before December 31, 2020. If you plan to continue the project, you need to request renewal of your ethics clearance and include a brief summary on the progress of your research. When the project no longer involves contact with human participants, is completed and/or terminated, you are required to provide an annual update with a brief final summary and your file will be closed. If you need to make changes during the project which may raise ethical concerns, you must submit an Amendment Request with a description of these changes for the Committee's consideration prior to implementation. If funding is obtained subsequent to approval, you must submit a Funding and/or Partner Change Request to ICEHR before this clearance can be linked to your award.

All post-approval event forms noted above can be submitted from your Researcher Portal account by clicking the *Applications: Post-Review* link on your Portal homepage. We wish you success with your research.

Yours sincerely,

Kelly Blidook, Ph.D.
Vice-Chair, Interdisciplinary Committee on
Ethics in Human Research

KB/bc

cc: Supervisor – Dr. Karen Goodnough, Faculty of Education

Appendix 4 – ICHER Protocol Amendment Approval Letter

MEMORIAL UNIVERSITY

Interdisciplinary Committee on Ethics in Human Research (ICEHR)

St. John's, NL Canada A1C 5S7
Tel: 709 864-2561 icehr@mun.ca
www.mun.ca/research/ethics/humans/icehr

ICEHR Number:	**20201143-ED**
Approval Period:	December 16, 2019 – December 31, 2021
Funding Source:	
Responsible Faculty:	Dr. Karen Goodnough Faculty of Education
Title of Project:	*High School Science Teachers' Professional Learning during Lesson Study for Student Inquiry*
Amendment #:	***01***

January 19, 2021

Mr. Patrick Wells
Faculty of Education
Memorial University of Newfoundland

Dear Mr. Wells:

The Interdisciplinary Committee on Ethics in Human Research (ICEHR) has reviewed the proposed revisions for the above referenced project, as outlined in your amendment request dated December 2, 2020, and is pleased to give approval to the revised online protocols, as described in your request, provided all other previously approved protocols are followed. However, before recruitment and data collection begin permission to conduct research must be obtained from the Newfoundland and Labrador English School District. If permission is obtained, please upload the NLESD application and permission documents using **ICHER – Post-Approval Document Submission** form.

If you need to make any other changes during the conduct of the research that may affect ethical relations with human participants, please submit an amendment request, with a description of these changes, via your Researcher Portal account for the Committee's consideration.

Your ethics clearance for this project expires December 31, 2021, before which time you must submit an annual update to ICEHR. If you plan to continue the project, you need to request renewal of your ethics clearance, and include a brief summary on the progress of your research. When the project no longer requires contact with human participants, is completed and/or terminated, you need to provide an annual update with a brief final summary, and your file will be closed.

Annual updates and amendment requests can be submitted from your Researcher Portal account by clicking the *Applications: Post-Review* link on your Portal homepage.

The Committee would like to thank you for the update on your proposal and we wish you well with your research.

Yours sincerely,

Kelly Blidook, Ph.D.
Vice-Chair, Interdisciplinary Committee on
Ethics in Human Research

KB/bc

cc: Supervisor – Dr. Karen Goodnough, Faculty of Education

Appendix 5 – Google Folder Link for Recruitment Letters and Informed Consent Forms

Research Recruitment Letter (Administrator)

My name is Patrick Wells, and I am a PhD candidate in the Faculty of Education at Memorial University of Newfoundland. I am conducting a research project called "**High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry.**" This study will examine teachers' and students' learning during lesson study professional learning. We will use Google Meet to allow teachers, school administration, and outside topic experts to collaborate remotely and develop two inquiry lessons of involve local topics, such as ocean ecology or local weather. I wish to recruit you, two members of your teaching staff, and their students to participate in this research which will investigate student and teacher learning experiences.

As part of this research, you and two teachers will form an online team with myself and a school to develop and implement two activities that focus student inquiry in science to address the skill outcomes in Science 1206 (using Google meet and sharing Google docs). A knowledgeable other, a subject area expert from a local environmental organization, will also support the lesson development. We will participate in collaborative planning/debriefing Google Meets throughout the school year to record the developing lesson and planning meetings. The administrative participants' role is less than that of the teachers with fewer lesson meetings, but I would like you to attend the lesson presentations and allow me to conduct two Google Meet interviews with you (a 30-minute pre-project interview and a one-hour interview at the end of the project during exams). This study will take place from September 10, 2020 and end on June 30, 2021. The activities for this project may total 10 hours and will occur during regular school hours or before 5 PM.

Students will take part in the online co-created learning activities as part of regular curriculum-based instruction. I would like to observe the students during the online class activities and record notes of their actions and interactions. We will examine some student work (writing, assignments, etc.) and ask students questions regarding their understanding of the lessons presented during lesson study professional learning. At no time will the school, teachers, and students be identified by name.

Participation in the study, for students, teachers, and administrators is voluntary and participants may withdraw from the study at any time. If student withdrawal occurs after June 25, 2021, data cannot be removed as data analysis will have started. Administrators and teachers have until August 30, 2021 to withdraw for their data to be removed.

If you have any questions about the project, please contact me by email at p.wells@mun.ca or by phone at 709 682-4945.
Thank-you in advance for considering my request,

Patrick Wells
PhD candidate
Memorial University of Newfoundland
The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as your rights as a participant, you may contact the Chairperson of the ICEHR at icehr.chair@mun.ca or by telephone at 709-864-2861.

Research Recruitment Letter (Teacher)

My name is Patrick Wells and I am a PhD candidate in the Faculty of Education, Memorial University of Newfoundland. I am conducting a research project called "**High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry.**" This study will examine teachers' and students' learning during lesson study professional development. We will use Google Meet to allow teachers, school administration, and outside topic experts to collaborate remotely and develop two inquiry lessons of involve local topics, such as ocean ecology or local weather. I wish to recruit you and your students, a member of your administration, another teacher (and their students) to participate in this research that will investigate student and teacher learning experiences.

As part of this research, you and another teacher will form an online team with myself and a school administrator, to develop and implement two activities that focus student inquiry in science to address the skill outcomes in Science 1206 (using Google meet and sharing Google docs). A knowledgeable other, a subject area expert from a local environmental organization, will also support the lesson development. We will participate in collaborative planning/debriefing Google Meets throughout the school year to record the developing lesson and the planning meetings. I will make observations during your remote classroom teaching of the lessons and you will need to participate in two Google Meet interviews (a 30-minute pre-project interview and a one-hour interview at the end of the project during exams). During final exams all the teachers from your school will form a focus group with the teachers from other schools to have a one-hour discussion of online professional learning with lesson study. This study will take place from March 1, 2021 and end on June 30, 2021. The activities for this project may total 20 hours and will occur during regular school hours or before 5 PM.

I would like to observe the students during the online class activities and record notes of their actions and interactions. We will examine some student work (writing, assignments, etc.) and ask students questions regarding their understanding of the lessons presented during lesson study professional learning. At no time will the school, teachers, and students be identified by name.

Participation in the study, for students, teachers, and administrators is voluntary and participants may withdraw from the study at any time. If student withdrawal occurs after June 25, 2021, data cannot be removed as data analysis will have started. Administrators and teachers have until August 30, 2021 to withdraw for their data to be removed.

If you have any questions about the project, please contact me by email at p.wells@mun.ca or by phone at 709 682-4945.
Thank-you in advance for considering my request,
Patrick Wells
PhD candidate
Memorial University of Newfoundland
The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as your rights as a participant, you may contact the Chairperson of the ICEHR at icehr.chair@mun.ca or by telephone at 709-864-2861.

Research Recruitment Letter (Science Adviser)

My name is Patrick Wells, and I am a PhD candidate in the Faculty of Education at Memorial University of Newfoundland. I am conducting a research project called "**High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry."** This study will examine teachers' and students' learning during lesson study professional learning. We will use Google Meet to allow teachers, school administration, and outside topic experts to collaborate remotely and develop two inquiry lessons of involve local topics, such as ocean ecology or local weather. I wish to recruit you, a member of the school administration, two members of the teaching staff, and their students to participate in this research which will investigate student and teacher learning experiences.

As part of this research, you will form an online team with two teachers, myself and a school administrator, to develop and implement two activities that focus student inquiry in science to address the skill outcomes in Science 1206 (using Google meet and sharing Google docs). As subject area expert from a local environmental organization, you are considered a science adviser, and will be asked to support the teachers' lesson development. We will participate in collaborative planning/debriefing Google Meets throughout the school year to record the developing lesson and planning meetings. I will make observations during your remote classroom teaching of the lessons and you will need to participate in two Google Meet interviews (a 30-minute pre-project interview and a one-hour interview at the end of the project during exams). This study will take place from September 10, 2020 and end on June 30, 2021. The activities for this project may total 15-20 hours and will occur during regular school hours or before 5 PM.

Students will take part in the online co-created learning activities as part of regular curriculum-based instruction. I would like you to observe the students during the classroom activities and help us examine some student work (writing, assignments, etc.) and determine their understanding of the lessons presented during lesson study professional learning. At no time will you, the school, teachers, and students be identified by name.

Your participation in the study is voluntary and participants may withdraw from the study at any time. As a science adviser for the project, you have until August 30, 2021 to withdraw for your data to be removed.

If you have any questions about the project, please contact me by email at p.wells@mun.ca or by phone at 709 682-4945.
Thank-you in advance for considering my request,
Patrick Wells
PhD candidate
Memorial University of Newfoundland
The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you

have ethical concerns about the research, such as your rights as a participant, you may contact the Chairperson of the ICEHR at icehr.chair@mun.ca or by telephone at 709-864-2861.

Informed Consent Form for Administrators

Title: High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry

Researcher: Mr. Patrick Wells, PhD Candidate, Faculty of Education, Memorial University of Newfoundland (email: p.wells @mun.ca)

Supervisor: Dr. Karen Goodnough, Faculty of Education, Memorial University of Newfoundland (email: kareng@mun.ca)

You are invited to take part in a research project entitled "High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry."

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researcher, Mr. Patrick Wells, if you have any questions about the study or would like more information before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

Introduction:
I am doctoral candidate in the Faculty of Education, Memorial University. As part of my Doctoral thesis I will study science teacher learning within the high school context using lesson study as a form of professional learning (PL). Lesson study is rarely used as PL in high school, yet lesson study improves teaching through teacher collaboration and a focus on teaching and student learning. I intend to collaborate online using Google Meet with teachers, school administration, and outside topic experts from the Conservation Corps or Memorial University, to collaboratively develop lessons that use inquiry of local topics, such as ocean ecology or local weather. My doctoral research is under the supervision of Dr. Karen Goodnough.

Purpose of Study:
This research will support two teachers of your school as they design curriculum-based learning activities to help students develop an understanding of local weather/climate and ecological sustainability. I want to investigate how online instructional planning during professional learning called *lesson study*, affects teachers' classroom practice and student learning in science. Time permitting, you will be an online collaborator as teachers develop and teach two inquiry lessons for the newly released curriculum as part of this process. This study will also examine

student responses and learning to help fully understand the impact of these online or face to face lessons.

What You Will Do in this Study:
Before the lesson development begins, I will introduce the participants to lesson study and student inquiry in science using traditional professional development. You are invited to participate in this online professional learning along with the other group members (myself, two teachers, and a subject area expert from the Conservation Corps or Memorial University). Google meet is the main online meeting application for NLESD and is chosen platform for this remote research as required by District research policies. Google meet allows for observation of teacher collaboration, chat, and people may only enter provide they have the secure link and are subsequently granted entry by the leader of the meeting. The teachers and I will conduct online lesson study professional learning for two lessons in consultation with you and the other group members. As a group of five or more we will participate in collaborative planning /teaching /debriefing using Google Meets throughout the school year. The teachers will conduct two cycles of lesson study (the teachers will teach the lessons which are evaluated by the group). The research lessons will address curriculum outcomes that involve student inquiry in science.

To the degree possible as an administrator, you will be asked to engage in a variety of activities during the study:
- Answer a set of pre-study questions during a phone or Google Meet interview.
- Attend or observe a one-day online workshop on lesson study and student inquiry (funding will be provided for substitute teachers).
- Attend and observe activities in lesson study planning meetings (4-6 times) throughout the school year.
- Observe two online or face to face lesson study lessons and assist in lesson evaluation (funding will be provided for substitute teachers).
-Record your ideas and thoughts in a professional multi-media online journal (Google Docs).
-Allow a researcher to collect data at planning meetings and during classroom visits.
-Use online learning tools, including the Google Suite, to support research, communication, and collaboration.
-Participate in a one-hour phone or Google Meet interview at the end of the year (during the June final exam period)

Participation in the study is voluntary and you may withdraw at any time. Withdrawing from this study, or any aspect of this study, is a private matter and your decision will be respected and not shared with anyone. If you do not participate in the study no data will be collected and the research lessons will be presented to all students in the same manner (the other teachers will not be aware if you are participating). In addition, during an interview you may choose to skip any interview question you do not wish to answer.

Length of Time:
This study will take place from January 10, 2021 and end on June 30, 2021. The activities for

this project may total 20 hours for teachers and 10 hours for an administrator and will occur during regular school hours or before 5 PM. This research project will provide substitute teachers to cover instructional time during the project.

Withdrawal from the Study:
Your participation in this study is voluntary. If you choose to participate, you are free to withdraw from the study at any time and also to withdraw any data that pertains to you if withdrawal occurs before August 30, 2021. However, data cannot be removed after August 30, 2021, as data analysis will have started. Confidentiality will be respected, and your identity will not be released or published without your explicit consent.

To withdraw from the study email the principal investigator, Mr. Patrick Wells (p.wells@mun.ca).

Possible Benefits:
Any professional learning will benefit your development and consequently your school's students. This study is beneficial because it provides an opportunity to explore and document student and teacher experiences during the online lesson study inquiry activities. Few studies in high school science have documented how lesson study impacts student and teacher learning. Lesson study and the lessons developed during this study may be used by the research participants and other teachers.

Possible Risks:
There are no risks associated with this study/project, aside from those associated with regular teaching and lesson preparation.

Confidentiality:
The ethical duty of confidentiality includes safeguarding participants' identities, personal information, and data from unauthorized access, use, or disclosure. Your participation in this study is voluntary. Confidentiality will be respected and your identity will not be released or published without your explicit consent. All data collected in the study will be confidential and pseudonyms and numbers will be used as identifiers on all data collected. After your interview, and before the data are included in the final report, you will be able to review the transcript of your interview, and to add, change, or delete information from the transcripts as you see fit.

Anonymity:
Every reasonable effort will be made to ensure your anonymity. For example, transcribers will be required to sign a confidentiality agreement to safeguard your anonymity. You will not be identified in publications without your explicit permission. However, the results of this study may be included in publications and reports. Using this information, readers could locate the site of the study and possibly identify your school as participants. If having you, your school or classes identified is a concern for you, we respect your decision not to participate in the study or to withdraw from this study in the manner outlined above.

Recording of Data:
Data from class observations will be written and then transcribed with a word processor. Student and teacher documents will be scanned into PDF format where all identifying names will be redacted. Recordings of interviews will be placed on a computer and transcribed with a word processor. Prior to data transcription participants will be assigned numbers as identifiers. All digital data will be stored on password-protected devices.

Use, Access, Ownership, and Storage of Data:
All data (teacher documents, observational notes, and interviews) will be stored in a locked cabinet in the office of the principal investigator. The principal investigator and supervisor will be the only two individuals who will have access to use the data for analysis. Data will be kept for a minimum of five years, as required by Memorial University's policy on Integrity in Scholarly Research. After five years of completing the research, all data will be destroyed, and data stored on password-protected devices deleted.

Reporting of Results:
Upon completion, my thesis will be available at Memorial University's Queen Elizabeth II library, and can be accessed online at: http://collections.mun.ca/cdm/search/collection/theses. This work will also be presented at conferences and published in scholarly journals. Data will be reported in both an aggregated manner and/or in a summarized format and direct quotations will be shared during dissemination (pseudonyms will be used).

Sharing of Results with Participants:
The results of the lesson study professional learning will be reviewed and prepared for publication on the Math Science Special Interest Council news letter and the NLTA bulletin.

Questions:
You are welcome to ask questions before, during, or after your participation in this research. If you would like more information about this study, please contact: Mr. Patrick Wells (p.wells @mun.ca)

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as the way you have been treated or your rights as a participant, you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Consent:
Your signature on this form means that:

- You have read the information about the research.
- You have been able to ask questions about this study.
- You are satisfied with the answers to all your questions.
- You understand what the study is about and what you will be doing.

- You understand that you are free to withdraw participation in the study without having to give a reason, and that doing so will not affect you now or in the future.
- You understand that if you choose to end participation **during** data collection, any data collected from you up to that point **will be retained by the researcher, unless you indicate otherwise**.
- You understand that if you choose to withdraw **after** data collection has ended, your data can be removed from the study up to Aug. 30, 2021.

I agree to being be audio-recorded during an interview	☐ Yes	☐ No
I agree to the use of my direct quotations	☐ Yes	☐ No
I agree that my lesson study actions and interactions may be observed and documented	☐ Yes	☐ No
I agree for my lesson study related work to be examined and used for research	☐ Yes	☐ No

By signing this form, you do not give up your legal rights and do not release the researchers from their professional responsibilities.

Your Signature Confirms:

☐ I have read what this study is about and understood the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions and my questions have been answered.

☐ I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation.

☐ A copy of this Informed Consent Form has been given to me for my records.

____________________________ ____________________________

Signature of Participant Date

Researcher's Signature:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

____________________________ ____________________________

Signature of Principal Investigator Date

Informed Consent Form for Teachers

Title: High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry

Researcher: Mr. Patrick Wells, PhD Candidate, Faculty of Education, Memorial University of Newfoundland (email: p.wells @mun.ca)

Supervisor: Dr. Karen Goodnough, Faculty of Education, Memorial University of Newfoundland (email: kareng@mun.ca)

You are invited to take part in a research project entitled "High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry."

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researcher, Mr. Patrick Wells, if you have any questions about the study or would like more information before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

Introduction:
I am doctoral candidate in the Faculty of Education, Memorial University. As part of my Doctoral thesis I will study science teacher learning within the high school context using lesson study as a form professional learning (PL). Lesson study is rarely used as PL in high school, yet lesson study improves teaching through teacher collaboration and a focus on teaching and student learning. I intend to collaborate online using Google Meet with teachers, school administration, and outside topic experts from the Conservation Corps or Memorial University to collaboratively develop lessons that use inquiry of involve local topics, such as ocean ecology or local weather. I am conducting research under the supervision of Dr. Karen Goodnough.

Purpose of Study:
This research will support two teachers of your school as you design curriculum-based learning activities to help students develop an understanding of local weather/climate and ecological sustainability. I want to investigate how your online instructional planning during professional learning called *lesson study*, affects your classroom practice and student learning in science. You and your online collaborators will develop and teach two inquiry lessons for the newly released curriculum as part of this process. This study will also examine student responses and learning to help fully understand the impact of these online or face to face lessons.

What You Will Do in this Study:
To prepare the teachers, I will introduce you to lesson study and student inquiry in science using traditional professional development. Then as pairs, you and another teacher will form online lesson study groups in your school. Google meet is the main online meeting application for NLESD and is the District chosen platform for this remote research; all district teachers have been trained to use it. Google meet allows for observation of collaboration, chat, and people may only enter provide they have the secure link and are subsequently granted entry by the leader of the meeting (note that CDLI teachers may use Blackboard collaborate to present lessons and this platform offers the same sharing and security features of Google Meet). You, your partner and I, will then conduct online lesson study professional learning with a school administrator, a knowledgeable other. As a group of five we will collaborative planning/debriefing Google Meets throughout the school year to record the developing lesson and planning meetings. You will conduct two online research lessons and as part of two cycles of lesson study. The research lessons will address curriculum outcomes that involve student inquiry in science.

You will be asked to engage in a variety of activities during the study:
- Answer a set of pre-study questions during a phone interview.
- Complete a one-day online workshop on lesson study and student inquiry (funding will be provided for substitute teachers).
- Attend and document activities in lesson study planning meetings (4-6 times) throughout the school year.
- Conduct two online or face to face lesson study lessons (one class each) and assist in lesson evaluation (funding will be provided for substitute teachers).
-Develop and implement activities that focus on improving aspects of student inquiry in science.
-Record your ideas and thoughts in a professional multi-media online journal (Google Docs).
-Allow a researcher to collect data at planning meetings and during classroom visits.
-Use online learning tools, including the Google Suite, to support research, communication, and collaboration.
-Participate in a one-hour phone interview and then a Google Meet focus group at the end of the year (during the June final exam period)

Participation in the study is voluntary and you may withdraw at any time. Withdrawing from this study, or any aspect of this study, is a private matter and your decision will be respected and not shared with anyone. If you do not participate in the study no data will be collected and the research lessons will be presented to all students in the same manner (the other teachers will not be aware if you are participating). In addition, during an interview you may choose to skip any interview question you do not wish to answer.

Length of Time:
This study will take place from March 1, 2021 and end on June 30, 2021. The activities for this project may total 20 hours for teachers and 10 hours for an administrator and will occur during

regular school hours or before 5 PM. The activities for this project may total 20 hours work and will occur during regular school hours. As teams, we will apply for funding from several organizations to obtain fund to support your work. If these applications are not successful, this research project will still provide substitute teachers to cover lost instructional time during the project.

Withdrawal from the Study:
Your participation in this study is voluntary. If you choose to participate, you are free to withdraw from the study at any time and also to withdraw any data that pertains to you if withdrawal occurs before August 30, 2021. However, data cannot be removed after August 30, 2020, as data analysis will have started. Confidentiality will be respected, and your identity will not be released or published without your explicit consent.

To withdraw from the study email the principal investigator, Mr. Patrick Wells (p.wells@mun.ca).

Possible Benefits:
Any professional learning will benefit your development and consequently your students. This study is beneficial because it provides an opportunity to explore and document student and teacher experiences during the online lesson study inquiry activities. Few studies in high school science have documented how lesson study impacts student and teacher learning. Lesson study and the lessons developed during this study may be used by the research participants and other teachers.

Possible Risks:
There are no risks associated with this study/project, aside from those associated with regular teaching and lesson preparation.

Confidentiality:
The ethical duty of confidentiality includes safeguarding participants' identities, personal information, and data from unauthorized access, use, or disclosure. Your participation in this study is voluntary. Confidentiality will be respected, and your identity will not be released or published without your explicit consent. All data collected in the study will be confidential and pseudonyms and numbers will be used as identifiers on all data collected. After your interview, and before the data are included in the final report, you will be able to review the transcript of your interview, and to add, change, or delete information from the transcripts as you see fit.

Anonymity:
Every reasonable effort will be made to ensure your anonymity. You will not be identified in publications without your explicit permission. For example, transcribers will be required to sign a confidentiality agreement to safeguard your anonymity. However, the results of this study may be included in publications and reports and using this information, readers could locate the site of the study and possibly identify your school and you as participants. If having your school or

classes identified is a concern for you, we respect your decision not to participate in the study or to withdraw from this study in the manner outlined above.

Recording of Data:
Data from class observations will be written and then transcribed with a word processor. Student and teacher documents will be scanned into PDF format where all identifying names will be redacted. Recordings of interviews will be placed on a computer and transcribed with a word processor. Prior to data transcription participants will be assigned numbers as identifiers. All digital data will be stored on password-protected devices.

Use, Access, Ownership, and Storage of Data:
All data (teacher documents, observational notes, and interviews) will be stored in a locked cabinet in the office of the principal investigator. The principal investigator and supervisor will be the only two individuals who will have access to use the data for analysis. Data will be kept for a minimum of five years, as required by Memorial University's policy on Integrity in Scholarly Research. After five years of completing the research, all data will be destroyed, and data stored on password-protected devices deleted.

Reporting of Results:
Upon completion, my thesis will be available at Memorial University's Queen Elizabeth II library, and can be accessed online at: http://collections.mun.ca/cdm/search/collection/theses. This work will also be presented at conferences and published in scholarly journals. Data will be reported in both an aggregated manner and/or in a summarized format and direct quotations will be shared during dissemination (pseudonyms will be used).

Sharing of Results with Participants:
The results of the lesson study professional learning will be reviewed and prepared for publication on the Math Science Special Interest Council news letter and the NLTA bulletin.

Questions:
You are welcome to ask questions before, during, or after your participation in this research. If you would like more information about this study, please contact: Mr. Patrick Wells (p.wells @mun.ca)

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as the way you have been treated or your rights as a participant, you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Consent:
Your signature on this form means that:

- You have read the information about the research.
- You have been able to ask questions about this study.

- You are satisfied with the answers to all your questions.
- You understand what the study is about and what you will be doing.
- You understand that you are free to withdraw participation in the study without having to give a reason, and that doing so will not affect you now or in the future.
- You understand that if you choose to end participation **during** data collection, any data collected from you up to that point **will be retained by the researcher, unless you indicate otherwise**.
- You understand that if you choose to withdraw **after** data collection has ended, your data can be removed from the study up to Aug. 30, 2021.

I agree to being be audio-recorded during an interview	☐ Yes	☐ No
I agree to the use of my direct quotations	☐ Yes	☐ No
I agree that my class related actions and interactions may be observed and documented	☐ Yes	☐ No
I agree for my work related to lesson study to be examined and used for research	☐ Yes	☐ No

By signing this form, you do not give up your legal rights and do not release the researchers from their professional responsibilities.

Your Signature Confirms:

☐ I have read what this study is about and understood the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions and my questions have been answered.

☐ I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation.

☐ A copy of this Informed Consent Form has been given to me for my records.

____________________________ ____________________________

Signature of Participant Date

Researcher's Signature:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

____________________________ ____________________________

Signature of Principal Investigator Date

Informed Consent Form for Science Adviser

Title: High School Science Teachers' Professional Learning During Online Lesson Study for Student Inquiry

Researcher: Mr. Patrick Wells, PhD Candidate, Faculty of Education, Memorial University of Newfoundland (email: p.wells @mun.ca)

Supervisor: Dr. Karen Goodnough, Faculty of Education, Memorial University of Newfoundland (email: kareng@mun.ca)

You are invited to take part in a research project entitled "High School Science Teachers' Professional Learning During Lesson Study for Student Inquiry."

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researcher, Mr. Patrick Wells, if you have any questions about the study or would like more information before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

Introduction:
I am doctoral candidate in the Faculty of Education, Memorial University. As part of my Doctoral thesis I will study science teacher learning within the high school context using lesson study as a form professional learning (PL). Lesson study is rarely used as PL in high school, yet lesson study improves teaching through teacher collaboration and a focus on teaching and student learning. I intend to collaborate with teachers, school administration, and you as a science expert, to collaboratively develop lessons that use inquiry of involve local topics, such as ocean ecology or local weather. I am conducting research under the supervision of Dr. Karen Goodnough.

Purpose of Study:
This research will support two teachers of your school as you design curriculum-based face to face or online learning activities to help students develop an understanding of local weather/climate and ecological sustainability. I want to investigate how your instructional planning during professional learning called *lesson study*, affects the classroom practice and student learning in science. Using only remote methods, you and your collaborators will develop inquiry lessons so teachers may instruct to address outcomes from the science released

curriculum. This study will also examine student responses during face to face or remote learning to help fully understand the impact of these lessons.

What You Will Do in this Study:

You have been asked to participate because of your knowledge in the area of the lessons we intend to develop for science students. Google meet is the main online meeting application for NLESD and is the District chosen platform for remote research; all district teachers have been trained to use it. Google meet allows for observation of collaboration, chat, and people may only enter provide they have the secure link and are subsequently granted entry by the leader of the meeting. Using online professional learning through Google Meet, I will introduce you and the other members of the lesson study group to the process of lesson study and student inquiry. Then we will form a online group where you, two teachers, a school administrator, and I, will conduct lesson study professional learning. Over the period of four-six months, our goal will be to develop two online research lessons and present these to students. The research lessons will address curriculum outcomes that involve student inquiry in science and as a group we will evaluate their effectiveness and suggest improvements to the online lessons – this is the goal of lesson study, to improve the lesson and in doing so, improve teaching.

You will be asked to engage in a variety of activities during the study:
- Answer a set of pre-study phone interview questions.
- Complete a one-day online workshop on lesson study and student inquiry.
- Using online technology, attend and document activities in lesson study planning meetings (4-6 times) throughout the study period.
- Assist in lesson evaluation as it is presented online.
- Allow a researcher to collect data at online planning meetings and during online classroom visits.
- Participate in a one-hour phone or Google Meet interview at the end of the year (during the June final exam period)

Participation in the study is voluntary and you may withdraw at any time. Withdrawing from this study, or any aspect of this study, is a private matter and your decision will be respected and not shared with anyone. In addition, during an interview you may choose to skip any interview question you do not wish to answer.

Length of Time:

The study will start in January 10, 2021 and end August 30, 2020. The activities for this project may total 15-20 hours work and will occur during regular school hours. This research project will cover travel expenses during the project.

Withdrawal from the Study:
Your participation in this study is voluntary. If you choose to participate, you are free to withdraw from the study at any time and also to withdraw any data that pertains to you if withdrawal occurs before August 30, 2021. However, data cannot be removed after August 30, 2021, as data analysis will have started. Confidentiality will be respected, and your identity will not be released or published without your explicit consent.

To withdraw from the study email the principal investigator, Mr. Patrick Wells (p.wells@mun.ca).

Possible Benefits:
Any professional learning will benefit your development and consequently your students. This study is beneficial because it provides an opportunity to explore and document student and teacher experiences during the lesson study inquiry activities. Few studies in high school science have documented how lesson study impacts student and teacher learning. Lesson study and the lessons developed during this study may be used by the research participants and other teachers.

Possible Risks:
There are no risks associated with this study/project, aside from those associated with regular online lesson preparation.

Confidentiality:
The ethical duty of confidentiality includes safeguarding participants' identities, personal information, and data from unauthorized access, use, or disclosure. Your participation in this study is voluntary. Confidentiality will be respected, and your identity will not be released or published without your explicit consent. All data collected in the study will be confidential and pseudonyms and numbers will be used as identifiers on all data collected. After your interview, and before the data are included in the final report, you will be able to review the transcript of your interview, and to add, change, or delete information from the transcripts as you see fit.

Anonymity:
Every reasonable effort will be made to ensure your anonymity. You will not be identified in publications without your explicit permission. For example, transcribers will be required to sign a confidentiality agreement to safeguard your anonymity. However, the results of this study may be included in publications and reports. Using this information, readers could locate the site of the study and possibly identify you through school participation. If being identified is a concern for you, we respect your decision not to participate in the study or to withdraw from this study in the manner outlined above.

Recording of Data:

Data from class observations will be written and then transcribed with a word processor. Student and teacher documents will be scanned into PDF format where all identifying names will be redacted. Recordings of interviews will be placed on a computer and transcribed with a word processor. Prior to data transcription participants will be assigned numbers as identifiers. All digital data will be stored on password-protected devices.

Use, Access, Ownership, and Storage of Data:
All data (teacher documents, observational notes, and interviews) will be stored in a locked cabinet in the office of the principal investigator. The principal investigator and supervisor will be the only two individuals who will have access to use the data for analysis. Data will be kept for a minimum of five years, as required by Memorial University's policy on Integrity in Scholarly Research. After five years of completing the research, all data will be destroyed, and data stored on password-protected devices deleted.

Reporting of Results:
Upon completion, my thesis will be available at Memorial University's Queen Elizabeth II library, and can be accessed online at: http://collections.mun.ca/cdm/search/collection/theses. This work will also be presented at conferences and published in scholarly journals. Data will be reported in both an aggregated manner and/or in a summarized format and direct quotations will be shared during dissemination (pseudonyms will be used).

Sharing of Results with Participants:
The results of the lesson study professional learning will be reviewed and prepared for publication on the Math Science Special Interest Council news letter and the NLTA bulletin.

Questions:
You are welcome to ask questions before, during, or after your participation in this research. If you would like more information about this study, please contact: Mr. Patrick Wells (p.wells @mun.ca)

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as the way you have been treated or your rights as a participant, you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Consent:
Your signature on this form means that:

- You have read the information about the research.
- You have been able to ask questions about this study.
- You are satisfied with the answers to all your questions.
- You understand what the study is about and what you will be doing.
- You understand that you are free to withdraw participation in the study without having to give a reason, and that doing so will not affect you now or in the future.

- You understand that if you choose to end participation **during** data collection, any data collected from you up to that point **will be retained by the researcher, unless you indicate otherwise**.
- You understand that if you choose to withdraw **after** data collection has ended, your data can be removed from the study up to Aug. 30, 2021.

I agree to being be audio-recorded during an interview	☐ Yes	☐ No
I agree to the use of my direct quotations	☐ Yes	☐ No
I agree that my class related actions and interactions may be observed and documented	☐ Yes	☐ No
I agree for my lesson study related work to be examined and used for research	☐ Yes	☐ No

By signing this form, you do not give up your legal rights and do not release the researchers from their professional responsibilities.

Your Signature Confirms:

☐ I have read what this study is about and understood the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions and my questions have been answered.

☐ I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation.

☐ A copy of this Informed Consent Form has been given to me for my records.

______________________________ ______________________________

Signature of Participant Date

Researcher's Signature:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

______________________________ ______________________________

Signature of Principal Investigator Date

Appendix 6 – NLESD Research Approval

PROG-309-B

Newfoundland & Labrador English School District

Research Approval Conditions

Date: June 29, 2020 Investigator(s): Patrick Wells

Research Title: High School Science Teachers' Professional Learning during Lesson Study for Student Inquiry

New Research Application: X Extension: Application Date Received: January, 2020

1. A list of potential schools for this research has been submitted. Yes [x] No [ ]

   Your request to conduct this research is: APPROVED

   Approved requests for research are subject to the conditions/requirements below:

2. Final approval to conduct this study will rest with the principal of each targeted school and the targeted group of teachers' students/parents where applicable.
3. Conducting the research will in **no way negatively impact instructional time for students and teachers.**
4. Conducting this research must not put any burden of responsibility on school administrators or other staff unless they specifically agree to it. **Such agreement must not negatively impact instructional time.**
5. **Participation in the study will be voluntary** and participants will be able to opt out at any time without prejudice. This must be clearly communicated to the participants at the outset.
6. For students under 19 years of age, **the researcher(s) must secure parental consent and confirm such consent with the principal before the research proceeds.** Students 19 years of age and older must provide their own consent. Regardless of age, youth must be clearly informed from the outset that they may refuse to participate, even if their parents consented to their participation.
7. Ensuring anonymity of participants and confidentiality of all data generated and collected throughout the research.
8. Before the research project can begin, **it must receive final approval from your university's Research Ethics Committee** and a copy of this approval must be sent to the Research Review Committee of NLESD as per the contact information listed below. 8a. Ethics Committee approval letter has been received [x] 8b. Not applicable [ ]
9. If there is potential risk in this research project that some participants may relive a traumatic experience which can cause emotional or psychological stress, counselling services and other appropriate supports must be available during and subsequent to the data collection process. **Researchers are responsible for providing such supports. This service will not be provided by the NLESD.**
10. A copy of the research findings and resulting papers/reports must be directed to the CEO/Director of Education or designate. Please provide update on report if not available within one year.
11. Research results must be made available to the schools involved and the individual participants who request them.
12. The Newfoundland and Labrador English School District takes no responsibility in conducting this research, and will not be held liable for any negative impacts relating to this research effort. **The full responsibility to organize and conduct this research rests with the researcher(s).**

Recommended by: ______________________ June 29, 2020
Research Review Committee

Signature of Approval: ______________________ June29,2020
Associated Director Education

Signature of Compliance: Patrick Wells Date: July 3/2020
Researcher

A signed copy of this form MUST be returned to the address below and to the potential schools before research can begin:

Attention: researchsubmissions@nlesd.ca

Newfoundland and Labrador English School District
95 Elizabeth Avenue

Appendix 7 – Summary of Day 1 PL

Online Lesson Study: Google Doc 1 - Teacher Research for Professional Learning

Patrick Wells, Memorial University, Ph.D. Candidate

Welcome!

Let's introduce ourselves, share why we joined the project and tell each other our best educational experience (as a teacher or student – your choice!)

Session one – Join the Google Classroom for Lesson Study!

(joining code - https://classroom.google.com/c/MjQ4MTMyOTE5NDE0?cjc=akqbkqz)

- What is inquiry? Watch the video for a simple Geo-Inquiry https://www.youtube.com/watch?v=WPy7-5rNNaU&t=51s and using the shared Google Jam Board, share your understanding.
- On your own, Read "The Many Levels of Inquiry" by Heather Banchi and Randy Bell.
- Answer the shared questions on Jam Board 2 Banchi and Bell.
- Discussion of the meaning of inquiry from Blanchard et al. (2010).

Break for refreshments

Session two

- Activity and Analysis – Conduct an inquiry for Unit 4 of Science 1206 – Mini-Earth inquiry (potential core activity). YouTube Video: https://www.youtube.com/watch?v=kyo1quvOGk8&t=6s
- How could you make this activity levels 1, 2, and 3? Is level 4 possible? What is POE?
- Discussion – How do the different levels of inquiry address the Integrated Skills Outcomes?
- Reflection Journal

Lunch Break

Session three (bring your Lesson Study Book!)

- What's my story?
- What is lesson study? Review the cycle, goals, and duties of members of the lesson study group.
- Lesson study group negotiation. With partners, you need to decide the lessons you will conduct, communication protocols, etiquette, structure, determine dates for lessons, and set out expectations for support.
- Reflection Journal

Closing remarks and setting dates for school online meetings.

Appendix 8. The Remote Science Inquiry Student Lab Document

Acceleration of an Object down a Ramp and Instantaneous Velocity

Resource:

Science 10: Section 6.2 pp. 246-253

Background Information:

The acceleration of an object down a ramp will depend on the incline of the ramp. **IF** friction is minimized and the ramp is smooth and flat (not bumpy), the acceleration of the cart down the ramp should be close to constant. We shall see!

A recording device (like a motion detector) can only measure displacement and time interval. To get the **average velocity** during any given time interval, the displacement is divided by the time for that interval. To get i**nstantaneous velocity** from a position-time graph, a tangent line is drawn at the instant of time in which you are interested.

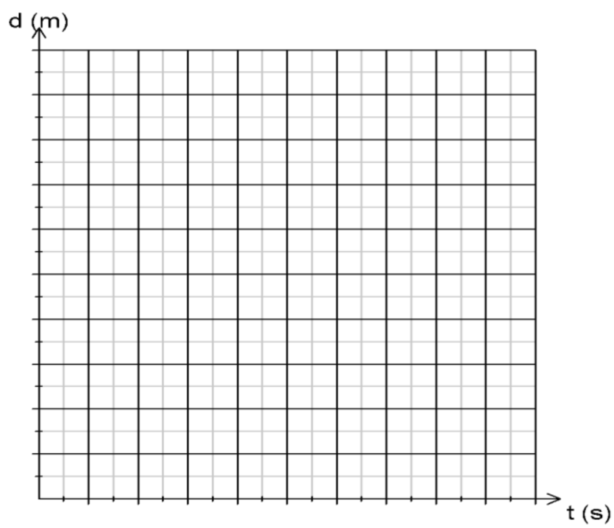
- The tangent touches the curve at exactly <u>ONE</u> point and has the same shape of the curve at that instant.
- You choose TWO points on the tangent line and using their coordinates, calculate the slope (rise/run) of the tangent line. (See example p. 247)

Purpose:

The purpose of this investigation is to investigate the motion of an object rolling down an inclined plane.

Hypothesis:

Predict the shape of a position-time graph for an object rolling down a ramp. Draw a sketch below and tell why you chose the shape you did.



Materials:

*List the materials used to set-up this activity.

Procedure

Refer to the steps below on how to make an inclined plane and measure displacement and velocity using the motion detector AND/OR watch **The video**

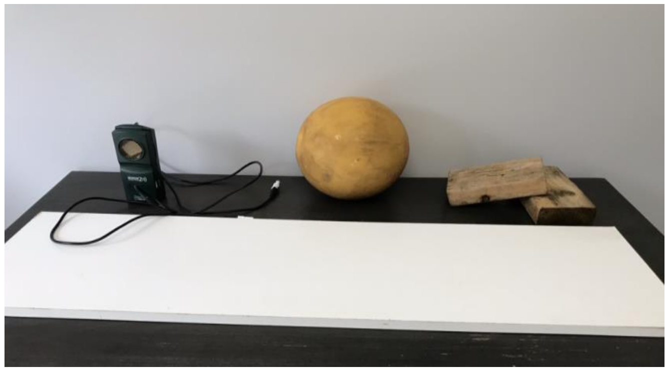
*Note any changes to the procedure and/or any safety precautions.

*While you are setting up and conducting the activity, think about possible sources of errors. And jot your observations here.

Materials used in the following demonstration set-up:

1. Plane board - 1m long x >0.20m wide x 0.015m thick (100cm x 20cm x 1.5cm)

2. Blocks (2”x4”)
3. Motion detector and cord
4. Ball



1. Make the Ramp - stack the blocks and lay the “plane” board on top.

2. Add the Motion detector - flip it open and make sure it is on the “ball” setting.

3. Make the sensor square as possible to the plane - you can use a ruler or a square.

4. Connect to the Vernier device as seen in the other videos and get ready to “roll”! □

5. Place the ball or movable object about 20 cm in front of the motion sensor - **START** the data collection - when you hear the sensor clicking, let the ball roll down the ramp.

*****Make sure you catch any devices before the roll of the desk/table !!*****

6. SAVE the graph you created and repeat the procedure again. Repeat until you have at least 2 "nice" graphs that represent the motion of the object moving down the ramp.

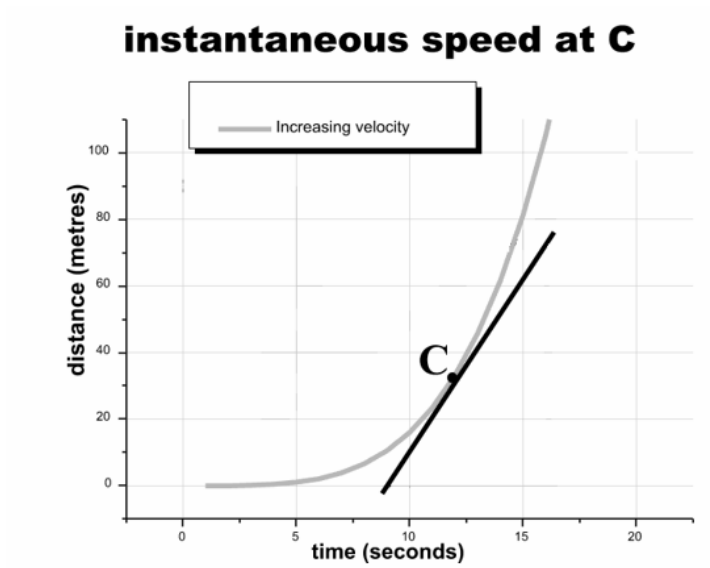
7. When you are content with your graphs, email copies to your teacher AND print a copy for yourself and each member of your group. You will need the printed copies to complete the rest of the lab report.

Results:

Include a copy of the graphs you created and/or the graphs provided.

Analysis:

Review the directions at the beginning of the lab (and on page 247) on how to calculate instantaneous velocity. See the diagram below:



1. Using the graphs you created and printed off, construct **THREE** tangents **on** the displacement-time graph at the times indicated by your teacher. Be sure that one of your tangents are drawn near the beginning of the motion when the object is just starting to move.

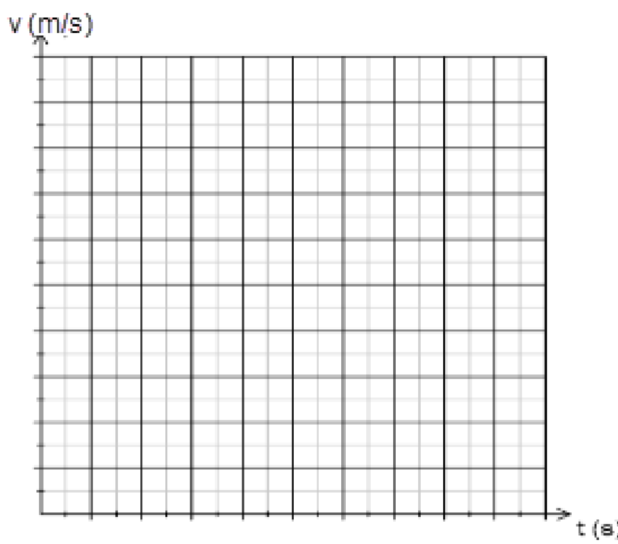
2. Find the velocity at the times indicated by calculating the slopes of the tangent lines, and complete the chart below. Show workings for tangent calculations.

Time (s)			

Velocity (m/s)			

Calculations related to Tangent 1:	Calculations related to Tangent 2:	Calculations related to Tangent 3:

3. a)Using your calculated values from (#2), draw a velocity- time graph.



b) Calculate the slope of your velocity-time graph. Show all your workings.

c) What does this slope represent?

d) Calculate the area under your velocity-time graph. Show all your workings.

e) What does this area represent?

Conclusion:

1. Look back at your hypothesis, comment on how close your predicted shape of the displacement time-graph was compared to the actual graph you created. Were you close. Why or why not.

2. After having conducted this activity. Describe what you have learned about the motion of an object rolling down an inclined plane. Be specific, use key terms and show your understanding.

Extension:

Check out and try out the Conclude and Apply Question 1on p. 253. Comment on your findings.

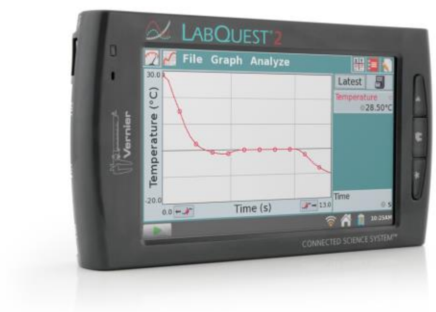
Appendix 9. The Google Doc with Hypermedia

What Vernier interface do you have? The video links below show you the apparatus you need and explain how to set up the interface for collecting data.

LabPro - this device requires a power supply (plug), USB cable to connect to the computer, a cable to connect the probe (motion sensor) and the computer must have a version of Logger Pro. [See this document for device cables].
This [video] demonstrates the LabPro set up and this [video] shows how to collect motion data.

LabQuest - this device requires a power supply plug but has an internal battery, USB cable to connect to the computer, a cable to connect the probe (motion sensor) and the computer must have a version of Logger Pro. This [video] demonstrates the LabQuest set up and this [video] shows how to collect motion data.

LabQuest2 - **this device requires a power supply but has an internal battery, USB cable to connect to the computer, a cable to connect the probe (motion sensor) and the computer must have a version of Logger Pro. This video demonstrates the LabQuest 2 set up and this video shows how to collect motion data.**



Appendix 10. The Cable Connection Google Doc.

What do the cables connect to? Scroll down to find your device.

LabPro - [video explanation]

LabPro Cable ends

To LabPro

To Computer

Motion Sensor to LabPro

LabPro to Motion Sensor

LabQuest - video explanation

LabQuest Cable  **To LabQuest**  **To Computer** 

LabPro to Motion Sensor 

Connect to SONIC on LabQuest (on right side)

LabQuest2 - video explanation

LabQuest2 Cable  **To LabQuest2**  **To Computer** 

LabPro to Motion Sensor  **Connect to SONIC on LabQuest2 (under rubber flap)**

Sample transcription of the video explanation link LabQuest2- Google Docs.mp4

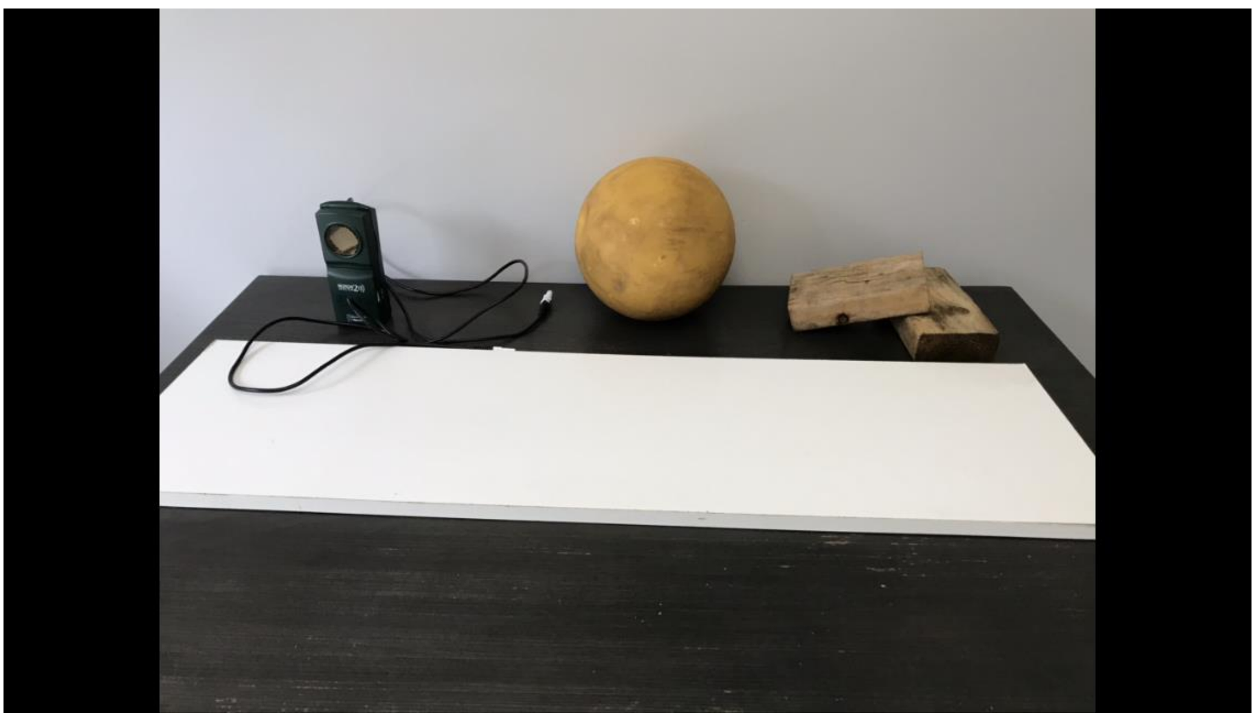
So you've got the lab test two and we want to be able to run it from the computer. We need to make those connections with the cable. So you've got this cable; it has two ends on it that are different. The smaller one is the one that goes into the lab quest and the port is along the side here. And it's the only one that has the same shape. It's just a USB port. This is the one that goes to the computer. Now we want to make sure that the lab quest is turned on, that you also have your sensor plugged in. Now, this one shows the motion sensor plugged in up here with the connector to both digital sonic ports of one of the lab quest, one of the motion sensors. Here's the motion sensor down here that has this cable coming in and it goes in digital side. Make sure you just put it in. Gently noticed that the digital side reports of the live cross to earn this little rubber flap sometimes are a little bit hidden or hard to find, but they are under a rubber flaps. So make sure you can locate those. All right. Once you have everything set up, the motion sensor connected and you're ready, then you plug it into the computer and then the screen will change in longer. Perot will take over. Make sure you got the GoPro up and running before you plug it in. OK, good luck.

Appendix 11. Making an Inclined Plane Google Doc with Transcription.

Making an inclined plane and measuring displacement and velocity with the motion detector. Read the document or watch the video :-)

Apparatus:

1. **Plane board - 1m long x >0.20m wide x 0.015m thick (100cm x 20cm x 1.5cm)**
2. **Blocks (2”x4”)**
3. **Motion detector and cord**
4. **Ball**



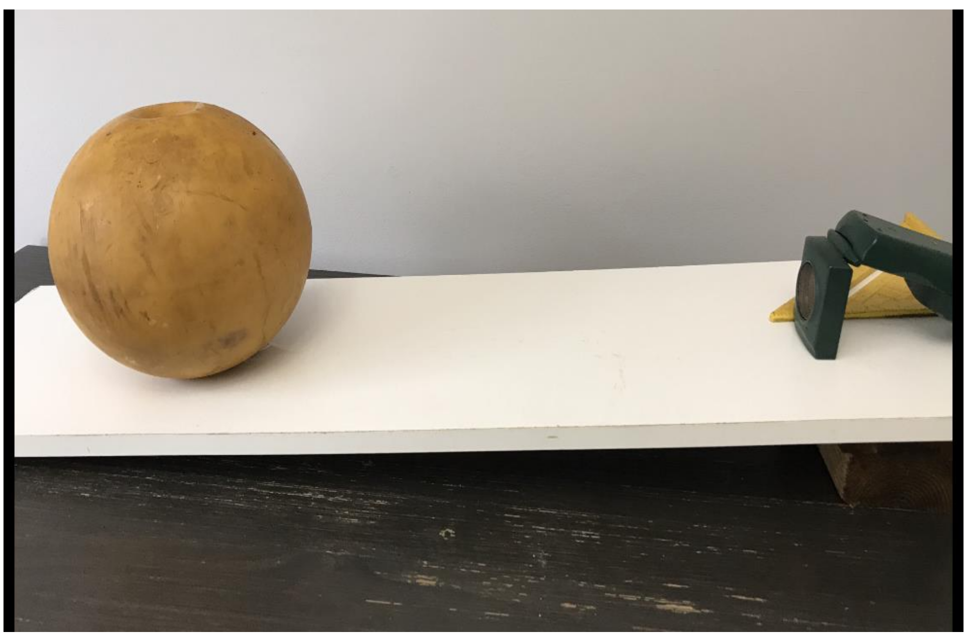
1. **Make the Ramp - stack the blocks and lay the “plane” board on top.**

2. **Add the Motion detector - flip it open and make sure it is on the “ball” setting.**

3. **Make the sensor square as possible to the plane - you can use a ruler or a square.**

Connect to the Vernier device as seen in the other videos and get ready to roll!

4. **Place the ball or movable object about 20 cm in front of the motion sensor - start the data collection - when you hear the sensor clicking, let the ball roll down the ramp. Make sure you catch any devices before the roll of the lab bench!**



What about errors? This is something that must be considered :-)

Transcription of Making an inclined plane - Google Docs.mp4

All right, folks, we want to show you how to make your income plain for doing your displacement velocity measurements with motion detector so you can put something in motion that just rolls down a hill. So what you're going to need is you're going to need your you're going to need your apparatus. You're going to need to block your plane board, which is about a meter long, 20 meters wide and about one point five centimeters thick and cut it there meters. And then I've got 10 centimeters afterwards. You're going to need some blocks of two by four. I just have to there right now, I have the motion detector and cord and of course, you've got your own device to connect it up to. And then I've got the ball. So let's just cut a little further here to make the ramp, just stack the blocks and then place your plane on the top where you're not putting anything heavy on top of it. So you're just making something that can allow something to roll down the plane, edge a motion detector on the top so you can flip it open and you can place it on the plane like this. All right. It's going to need a little bit of room there and notice how I've got an angle. So that's pointing down the plane. So we're going to do is going to roll something down the plane, not push something up, make the sensors square as possible. You can use a ruler if you want. You see, I've got a set square here and I've got the bottom and the front part of the the motion sensor lined up. So that is pointing directly down. The plane now connecter vernier device to the motion sensor, then connected to your longer probe through your computer. And let's get rolling here. So place the ball immovable object about 20 centimeters out in front of the motion sensor. All right, start the data collection and when you hear the clicking, let the ball roll down the ramp. Make sure you catch it before it goes flying off the bench. But you should be able to get a good amount of data. All right. But be sure to wait for the clicking to start, then set the ball in motion down the hill. All right. So' there it is on its way down. And another final thing I want to just say before we stop here is make sure you consider your errors. OK, this is why we use the 90-degree angle option. You can see it a little bit better up here. And you can see the motion sensors pointed at the devices is going down the hill. But there are errors. And you may find that I've used a very smooth ball here, but it does have imperfections on it. What about a basketball or a soccer ball? Depends what you use. All right. So good luck with setting up the plane and using your motion sensor and logger pro to collect some data from something that's rolling down a hill.