# An analysis of the professional learning of science teachers using the metaphor of learning by expanding

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This study reports on the professional learning of two teachers of science who were learning to engage their grade four students in meaningful, hands-on learning. Teachers' learning took place in the context of a 10-month university-based action research program designed to help improve the practice of science, technology, engineering and mathematics (STEM) Kindergarten to grade 9 teachers. Post-project analysis relied on Cultural Historical Activity Theory and its principle of expansive learning. Findings revealed that expansion of teachers' community served as a catalyst in their adoption of new tools. These included action research tools, pedagogical tools and information and technology tools. To capitalise on the affordances of the tools, the norms and division of labour needed to expand. Norms of practice shifted to an iterative process of design, implementation and observation and redesign of students' learning. Teachers expanded the division of labour from a position of vertical, teacher-centred direction and instruction to one in which they became facilitators of learning.

## Introduction

This paper reports on the professional learning of two, generalist, grade 4 teachers of science in rural Newfoundland and Labrador, Canada. The teachers participated in a 10-month long project that is part of a five-year program of action research led by a university researcher. The program is designed to help Kindergarten to Grade 9 STEM teachers (science, technology, engineering and mathematics) improve their practice. Professional learning has an important role to play in helping teachers improve their practice as STEM teachers. Improvement in practice is highly relevant, particularly for generalist elementary teachers who may not have studied science or who may have limited STEM pedagogical knowledge. Gambhir, Broad, Evans and Gaskell (2008) argued that a shortage of qualified mathematics and science teachers has resulted in a subsequent reliance on generalist teachers who are responsible for teaching science yet who may be lacking in any foundation in science or math.

While the need for professional learning may be well established, such is not the case for how it can best be designed and implemented. School-university partnerships offer opportunities for professional learning. However, universities have often taken a top-down, "expert knowledge givers", "something wrong with the schools" approach (Yamagata-Lynch, 2003a, p. 593). In this study, teachers' professional learning was guided by action research (AR). As an iterative and "methodical process of inquiry" (Stringer, 2007), AR offers a collaborative approach to professional learning that situates learning within the actual contexts of teachers' practice. It is beyond the scope of this paper to describe AR since it has been the focus of much research literature (see Kemmis & McTaggart, 2000; McNiff, 2002) and its value in teacher education has been well-established (see Mills, 2011; Sagor, 2000; Somekh, 2005; Stringer, 2013). The AR in this

study engaged teachers in a process of learning whereby they explored and examined new tools, norms and roles and designed and redesigned new approaches to their practice. While there are many forms of AR (see Kemmis & McTaggart, 2000), what is important in all forms is the process of inquiry conducted by and for those taking action (Sagor, 2000).

Post-project, we analysed teachers' learning using cultural historical activity theory (CHAT) (Engeström, 1987). CHAT analyses have been used to study teachers' change in practice (e.g., Davies, Howes & Farrell, 2008), teachers' professional development involving technology (e.g., Yamagata-Lynch, 2003b) and workplace learning in general (e.g., Worthen, 2008). In CHAT, the focus is not on the individual as the unit of analysis but on the activity system (Blackler, 2009) with its components of subject, object, community, tools, division of labour, norms and outcomes. Reliance on this unit of analysis "allows researchers to map out relationships of various elements within research participant activities" (Yamagata-Lynch & Haudenschild, 2006, p. 6). Use of the activity system provides a lens to interpret and analyse professional activity and its motives, the communities in which activity takes place, the norms that regulate activity, and the tools that individuals use to fulfil the object of activity (Hopwood & McAlpine, 2007). Engeström and Sannino (2010, p. 6) summarised the activity system components as follows:

> .... subject refers to the individual or subgroup whose position and point of view are chosen as the perspective of the analysis. Object refers to the 'raw material' or 'problem space' at which the activity is directed. The object is turned into outcomes with the help of instruments, that is, tools and signs. Community comprises the individuals and subgroups who share the same general object. Division of labor refers to horizontal division of tasks and vertical division of power and status. Finally, rules refer to the explicit and implicit regulations, norms, conventions and standards that constrain actions within the activity system.

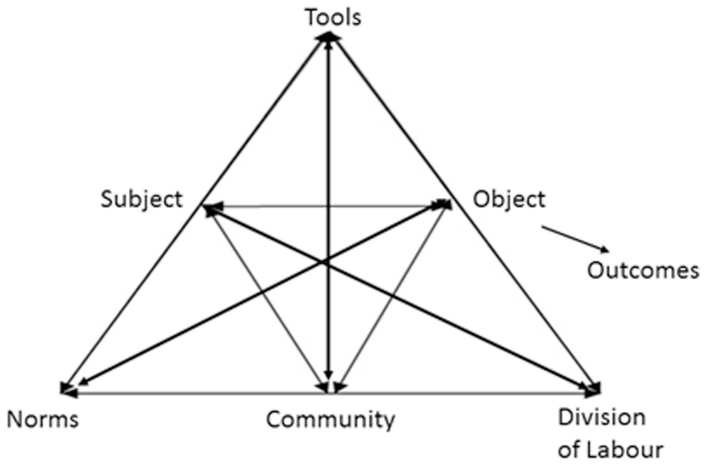


Figure 1: An activity system with its interacting components
(adapted from Engeström, 1987)

Use of the activity system as the unit of analysis is a CHAT principle. Another important CHAT principle is that of expansive learning. Thinking of professional learning in terms of expansion is relevant in a context of AR in which practitioners are working to transform their practice.

> Expansive learning involves the creation of new knowledge and new practices for a newly emerging activity; that is, learning embedded in and constitutive of qualitative transformation of the entire activity system (Daniels, 2004).

Expansion of teachers' practice means that it encompasses qualitatively more possibilities than does the previous form of activity, i.e., before the professional learning. Engeström and Sannino (2010) posited that "traditional modes of learning deal with tasks in which the contents to be learned are well known ahead of time by those who design, manage and implement various programs of learning" (p. 4). Examples of these 'traditional modes' might be professional development initiatives in which teachers are taught a new approach. In contrast to traditional learning, expansive learning involves learning "something that is not yet there" (p. 2). This form of learning is not merely a process of acquisition, transmission, or vertical improvement. It is one of expansion or "qualitative transformation" (p. 8) to embrace a wider range of possibilities. In contrast to acquisition or participatory metaphors of learning (see Sfard, 1998), this form of learning involves attempting to bridge the zone of proximal development (Vygotsky, 1978) or what Engeström (1987) referred to as "the distance between the present everyday actions of the individuals and the historically new form of the societal activity…" (p. 174). The societal activity, in this case, is the practice of teaching science.

In spite of CHAT's value in helping to make sense of teachers' professional learning, in general, there is a dearth of applications of CHAT to research on science teaching and teachers (Forbes, Madeira, Davis & Slotta, 2009). In relation to studies that use a CHAT lens to understand applications of AR to the teaching of science, we identified only one study. Wilson (2004) conducted a CHAT analysis of data collected from three beginning mentored teachers in a university-school partnership. Wilson found that use of a new tool in the form of a planning protocol provided the teachers with a means "to reflect on their practice" (p. 607). The tool was necessary because, as Wilson's analysis revealed, curriculum changes, testing, "content-laden prescribed curriculum" combined with "adverse budget situations" in schools resulted in science teachers lacking the time to critically evaluate their practice (p. 606). We also identified five other studies. These focused on mathematics (Junor Clark & Fournillier, 2012), mentored learning in pre-service education (Orland-Barak & Becher, 2011), academic language and learning support in an online third year computing course (Behrend, 2014), imaging technology (Feldman & Weiss, 2010) and *Every Child Matters* outcomes (Stuart, 2012).

The study reported on in this paper adds to this small body of research that combines AR and CHAT in science education. It is the only such study conducted in Canada that was uncovered in the review. Wilson's (2004) study with science teachers was conducted at the secondary level, whereas this one is with elementary teachers. Our focus, unlike in

Wilson's or in these other studies, is specifically on CHAT's principle of expansive learning which we rely on to analyse how teachers learned and transformed their practice.

### Purpose and objective

The purpose of the study reported on in this paper was to engage two grade-four teachers in professional learning to help them improve their teaching of science. The purpose of this paper is to make sense of the teachers' learning by analysing it using CHAT. The study was guided by the following research question: How did teachers' participation in professional learning result in expansion of their activity system and change in their practice?

## Methods

### Research context

The professional learning of the two teachers was part of a larger, province-wide five-year AR program with approximately 70 teachers per year. The program offers Kindergarten to grade 9 professional learning in science, technology, engineering and mathematics (STEM). The AR process adopted in the program involves planning a change, implementing the change, observing the outcomes of the change, and reflecting on the outcomes of the change (Kemmis & McTaggart, 2000). The university researcher (principal investigator) sent an invitation to the local school district inviting K-6 teachers to be part of the study. A district program specialist then distributed this invitation to schools. Teachers could then contact the principal investigator to obtain more information about the project before deciding to voluntarily participate. In the program, teachers worked in groups of two and each group selected a different area of inquiry. In this study, we report on two grade-four teachers of science, Fran and Patricia (pseudonyms) who volunteered to participate. They received five release days to engage in planning and implementation along with a small budget for the purchase of consumable materials.

### Data collection

The data came from five sources as follows: teachers' pre-implementation structured, written, *Inquiry Brief*; teachers' ongoing, structured, written reflections; post-implementation, individual semi-structured interviews with teachers; teachers' dissemination of their results to other teachers in multimedia format; and teachers' lesson plans. The *Brief* consisted of 16 prompts that included but were not limited to the following: research question; problem, dilemma, and/or issue; strategy; intervention; data collection and analysis. The lesson plans were jointly prepared and focused on the unit of light. Like the *Brief* and lesson plans, the final multimedia presentation was a collaborative product. Its creation provided teachers with an opportunity to not only synthesise their learning, but to describe to others in the program how they implemented a new approach to teaching.

The structured reflections included five prompts to which each teacher responded on a regular basis. The AR facilitator relied on teachers' reflections to inform her support of the teachers. The prompts were as follows:

> Describe, briefly, what was implemented or done during the week; How did students respond to the implementation? Did implementation go as expected? Why or why not? What new insights are you developing about your topic? About student learning? About your own teaching? As you analyse and collect data, are you finding answer to your research question? Please elaborate. Are new questions arising? Please share them.

The AR facilitator (principal investigator) conducted individual interviews at the end of the project. These lasted approximately one hour and were semi-structured with open-ended questions allowing for additional comments by the interviewer and interviewees. One set of questions pertained to the teachers' pedagogical and subject-specific knowledge of science. The next set probed teachers' perceptions of student learning and their response to the implementation. Four questions probed teachers' knowledge of self and personal growth throughout their participation. A final set of questions asked them if they had changed their research question or generated new questions and whether their future teaching may be impacted positively or otherwise by participation.

### Data analysis

CHAT guided our data analysis. This means that the overall unit of analysis was of the activity system. CHAT analysis involves portraying the activity system in terms of its components and, in this case of this study, analysing teachers' changes in practice in terms of the metaphor of expansion. Application of CHAT to contexts of professional practice serves as what Thorne (2005) referred to as "a set of heuristics and tools that can (and should be) situationally adapted" (p. 395). In contrast to a metaphor of learning as acquisition that might ask what knowledge teachers have gained, the metaphor of expansion requires analysis of the qualitative transformation of teachers' activity in terms of the system's components.

We first aggregated all sources of data into one file within which we separated the text with headings to distinguish between Fran's versus Patricia's reflections and interviews. The *Brief* represented a joint document. Once the data were aggregated, two coders (the two authors) read and reread the text to formulate an overall portrait of their activity system or practice as teachers of science. Russell (2001) noted that since "the world does not come neatly divided into activity systems" the researcher should "define the activity system based on the purposes of the research study" (p. 67). We relied on Table 1 to guide our coding.

## Findings

Fran was an early career (5th year) teacher. Although she had received professional development in language arts and in mathematics, she had had few opportunities for

Table 1: Activity system components, description and examples

| Component | Definition (adapted from Engeström, 1987) | Examples |
|---|---|---|
| Subject | Individual whose agency is the point of view in the analysis. | What are their characteristics? |
| Object | 'Problem space' at which the activity is directed. | What is the subject's purpose for engaging in the activity? |
| Norms | Norms and conventions that constrain actions. | What is the subject using tools to do? |
| Community | Individuals who share the object. | Who else is engaging in the activity with the subject? |
| Division of labour | Horizontal division of tasks and the vertical division of power and status. | What is the subject's position in terms of control of and power in the activity? |
| Tools | Physical and symbolic, external and internal mediating instruments. | What tools is the subject using to carry out activity? |
| Outcomes | Results from acting on the object, (intended or unintended). | What resulted from engaging in the activity? |

science professional development. She was not "100% comfortable" in science, did not feel like "the pro in any sense," and believed she had "lots of room to grow and learn." Patricia was a mid-career (20th year) teacher. Like Fran, she did not feel "comfortable in science or technology." She did not have "a lot of experience in science" or a "science mind". In fact, her initial degree was music education. She added, "when it comes to science ... I used to shy away from it." She noted that, "every time" she "tried an experiment, it did not come out right" and that her teaching was a "little flat." She was "frustrated" by her teaching experiences and lacked enthusiasm for teaching science which made it harder to bring out that enthusiasm "in the children."

The AR project was designed to provide them with supports and scaffolds that would compensate for their lack of comfort, confidence and expertise in the teaching of science. An essential part of that support came from expansion of their community to include collaboration with each other and with the AR facilitator. Their collaboration with the facilitator began with a week-long introductory session at the university. During this planning phase, the teachers first learned about the nature of AR. They then learned how to identify an area of focus, how to plan, formulate research questions, and how to collect and analyse data in relation to those questions. They also learned about various approaches to teaching and learning science.

The project also helped them expand their tools. The first of these tools was the AR process. This process involved planning for change, implementing the plan, observing and then reflecting on the outcomes of the change. This was a process they would rely on to guide their learning. The AR project also taught them to use the tool of the *Inquiry Brief* which they could complete throughout the planning process to guide their decisions about and discussion of the implementation. In this *Brief*, they articulated the object of their activity. Fran and Patricia wanted to improve their "teaching strategies [and] ... make the delivery of the science program more interesting to students." Fran wanted to make

"learning a little bit more meaningful and significant to them [students] .... a bit more relevant" by engaging them in "hands-on activities", because that is what students "enjoy." She also wanted to "grow" in technology because it was "a very effective method of communicating and educating today's students." She wanted to pay "closer attention to" teaching practices, recognise areas for "growth as a teacher" and "have better insight into [her] student's understanding..." Likewise, Patricia was interested in looking at the curriculum "from a different light" and attempting to gather data to support questions about her practice.

Other tools that they relied on included, as part of the planning phase, three release days to study curriculum documents and prepare their plan of action. As part of their planning, Fran and Patricia began identifying the tensions in their practice, i.e., elements that could interfere with or contradict achievement of the object. The tension they identified was that of time. Fran explained: "… the time is very, very valuable but also very compressed in a sense where a lot of the opportunities for hands-on exploration aren't really allotted because the instruction takes a certain amount of time…". Fran and Patricia collaborated to come up with a means to address this contradiction. The AR facilitator had provided an overview of various models and approaches to help change their practice. From these, the teachers decided to adopt the flipped classroom model. The model relies on technology "to move lectures outside the classroom and uses learning activities to move practice with concepts inside the classroom" (Strayer, 2007, p. 171). Fran described their decision to adopt the flipped classroom model:

> You don't have the time or the resources to get these hands-on activities and that's what we know our kids enjoy. That's what's meaningful for them and that is the type of activities that really contribute to their learning. So that's why we thought [of] the flipped classroom model…

Continuing with their planning, Fran and Patricia needed to come up with a research question. Research questions in an AR context represent a tool designed to scaffold and direct teachers' inquiry into their practice. They articulated their research question in the *Brief* as follows: "We wanted to know how the flipped classroom model is going to enhance student understanding in the Grade 4 science light unit…". The adoption of this flipped model meant that they needed to further expand their repertoire of tools. They located and read articles on the flipped classroom. They viewed a webinar on the topic. They then realised they needed an online space for parents and students to access science content outside of the regular classroom. Fran explained how they adopted information and communication tools for this purpose:

> We had to first introduce a tool to help us implement this flipped classroom model and … we looked at using *Edmodo*, an educational website for teachers and students to create an online classroom.… We used *Edmodo* as a tool to upload videos and audio files and used this to create our online environment…

Fran and Patricia explained that they liked the "visual appeal" of Edmodo, that they "could post pictures and videos" and "conduct polls and surveys" and that "parents could also set up an account and monitor their child's learning". However, in order to learn how

to use this tool in conjunction with the flipped model and with the curriculum outcomes, they needed support from a curriculum specialist. They, therefore, expanded their community to include the district enrichment coordinator who offered "insight as to how to integrate this technology" and how to match "specific curriculum outcomes for the unit" to the teachers' resources.

The coordinator introduced them to yet another new tool, *Screencast-O-Matic* that they relied on to record videos they created related to the various curriculum outcomes. Next, they began planning their units and lesson plans. The final step before implementation involved yet another expansion of their community to include parents. Fran explained: "... we also had an evening where we invited ... the parents of our students." During this meeting, they showed them how to use the new online spaces designed for learning "how to set up parent account so the parents were able to follow the progress and to be more in touch with what the students were doing..."

One the planning stage was finished, Fran and Patricia began the implementation. The implementation involved working towards achievement of the object of changing their practice to promote more meaningful, relevant, hands-on learning in science. They were supported in the implementation as Fran explained, by "collaboration with one another" as well as collaboration with the AR facilitator with whom they were regularly "discussing back and forth…". The AR facilitator also visited their classrooms to observe, answer questions, and provide input and guidance. Since the teachers were working in a rural community far from the university, some of their collaboration with the facilitator included reliance on technology (e.g., email and *Skype*).

Implementation meant putting into practice use of the flipped model. However, the model could not simply be mapped onto the existing norms in their practice. These norms involved, as in Fran's classroom "standing in front of the classroom, reading over the pages, answering questions, having discussions and doing some forms of experiments but not really given ample time for the exploratory activities…" Fran explained how they initially expanded the norms through implementation of the model:

> … we gave the students the opportunity to do their homework in terms of watching videos or listening to an audio recording with visuals, before they came to the classroom to give the teachers the opportunity to… engage in activities such as more hands-on activities for our students to make their science experience more meaningful to them…

Patricia gave an example of these types of hands-on activities in which they engaged students:

> Students worked in small groups with assigned tasks to answer the question – can light travel in a curved path? .... They then had to view an informational video clip, and find examples of light sources and closely look at the path the light takes. They then created a poster with sketches of what they found.... They problem solved what would be needed to curve that path of light. They shared their findings through oral language strategy – double circle, where I timed the conversations and students rotated.

Just as the flipped model required adoption of new norms, so did the AR process require new norms. Instead of merely teaching their students, Fran and Patricia needed to adopt an inquiry stance. This meant that they needed to begin observing the outcomes of use of the new tools and norms, reflecting on those observations and subsequently acting on them. Fran described how they gauged the effectiveness of the activities and gained deeper insights into how and what their students were understanding: "I was recording my data using my camera. I was using my *iPhone* to record data, like listening to student conversations." She added:

> They [students] got a chance to work together in their small groups to discuss and talk about natural sources of light. Then they had the blog to create on it after. So that allowed me to reflect on what they know…. as a teacher it helps me understand where my students are coming from and know more about the experiences that [they] are having and helping them understand these things….

Throughout this process, the teachers reflected on their practice, what they were learning, what was working and not working and what they needed to change. An example of one of Patricia's reflections highlights how she was drawing conclusions about what worked with the new classroom norms:

> The students enjoyed this lesson once again – they would much more prefer to have activities over written tasks. I still think that creating written responses are important to student development but much more effective after the exploring and oral sharing have been completed.

One of Fran's reflections highlighted her efforts at troubleshooting and problem solving.

> Some of my students are having difficulty with opening files that I am posting on *Edmodo* at their home computers. I am demonstrating for my students in school how to open these files, but there may be privacy settings or some other factors which are making it difficult for my students to open these files.

Just as use of the new tools required expansion of the norms, so too did it require expansion of the division of labour. Prior to participation in the project, as Fran explained, the curriculum was "laid out in a certain way" and "the sole responsibility is on the teacher for instruction of the material." Similarly, prior to participation, as Patricia observed rather than being a facilitator, she played more "the role as a teacher." Once they began using the new tools, however, Patricia had to become "more of a facilitator than a teacher…. guiding them [students] through the curriculum." Her role was to "clarify things for the students, question, and explain." She discovered that "eliminating the teacher talk/explain method to students as direct instruction – really allows more time for hands-on activities." She explained that, although she exercised "control as a teacher," the students had "a lot of control over their learning as well." Likewise, Fran "stepped away from [the] traditional, stand-up in the middle of the classroom role to monitoring small groups." She added regarding her students that "they were working with one another and learning from one another more so than listening to [her] all afternoon...".

The use of *Edmodo*, the online classroom, provided them with an opportunity to observe from a distance rather than engaging in direct instruction as Fran explained:

> We were sort of like the facilitator of the website and getting them used to going on this website, taking active participation with it, posting comments, answering questions, completing assignments, taking polls, [and] commenting on one another's comments or questions...

At the end of the project, Fran and Patricia continued to reflect on what they had learned. Fran commented that she had learned to "learn from the experiences of others." In their multimedia presentation, they referred to how they planned to continue with this new approach to learning, not only in science but in other areas:

> A change that we will make in our own practice is that we will provide rich, hands-on experiences for the children... This does not only have to only apply to the content of science as it can be cross-curricular. We will be more willing to allow students to take ownership of their learning and this flipped model not only allows for this but it also can give parents an opportunity to follow and play and active role in their child's learning.

Figure 2 summarises their expanded activity system.

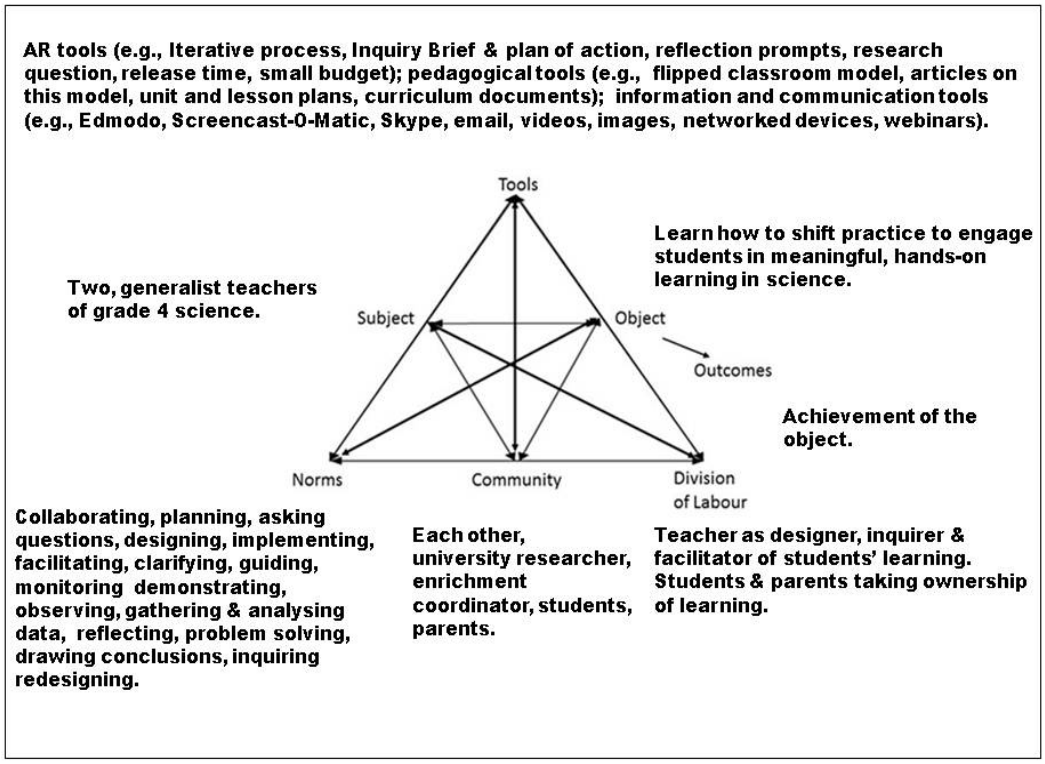


Figure 2: Teachers' expanded activity system

## Discussion and conclusion

This paper has provided an example of how we can think of teachers' professional learning as a complex system. A systems perspective "assumes that there are various dynamics at work in social behavior and these interact and combine in different ways" (Opfer & Pedder, 2011, p. 378). Using CHAT, we focused on that system in terms of interacting components. More importantly, using CHAT, we focused on the object of teachers' learning and on how components of the activity system expanded for teachers to improve their practice. Expansion of the community was a necessary first step because it provided scaffolds and supports to compensate for the teachers' lack of confidence and knowledge. The supports helped them integrate new tools. However, to take advantage of the affordances of these tools, the teachers had to alter their division of labour and their classroom norms. In general, therefore, we conclude based on our findings, that the two key components related to teachers' professional learning in this context were the expansion of the community and of the tools.

The importance of community in this study is a reminder of how others can scaffold teachers' learning and support them in ways that compensate for lack of confidence, knowledge or expertise. These supports may be of particular importance for generalist teachers. In contexts of professional learning where it is not possible to have a university partnership, colleagues and mentors can potentially provide these supports. Ferguson-Patrick (2011) concluded that there is a need for policy makers to ensure teachers receive "opportunities to examine and improve their own skills and knowledge of the profession under the guidance of more knowledgeable and experienced practitioners" (p. 109). Likewise, collaboration in professional learning, for example, between teacher teams, has "the potential to achieve significant improvements in teaching effectiveness" (Graham, 2007, p.1). Stoll, Bolam, McMahon, Wallace and Thomas (2006) argued that professional learning communities "hold considerable promise for capacity building for sustainable improvement" (p. 221). In general, professional learning communities play an important role in teacher and students' learning (Hord, 2004). In cases where teachers interested in professional learning do not have access to AR opportunities or university partnerships, there are also opportunities to join online professional communities (e.g., Lock, 2006).

The role of tools in this study highlighted the fact that activity, be it learning to teach or teaching on its own, is mediated by tools. In all activity systems, subjects' action on the object is mediated by tools. In this study, teachers expanded the tools to include the flipped classroom model and the online website *Edmodo*. These are examples of 'disruptive' tools that teachers can implement in their classrooms to overcome the rigidity of norms and conventions characteristic of some school practices. The teachers' use of *Edmodo* corresponded with Wallace's (2014) recommendation that it serves as a tool for collaboration and communication as well as instruction. He added that *Edmodo* "engages the teacher in risk-taking" (p. 293) and represents a social-networking tool that can "help facilitate a sustained ecological change in classrooms" (p. 294).

Our findings suggest that the flipped model can serve as an impetus or catalyst for teachers to dramatically change the norms and division of labour in their practice and that it can be, therefore, a valuable tool for professional learning and for transformation of practice. There is support in the literature for the role of the model in "promoting a more interesting and interactive teaching style" (Ronchetti, 2009, p. 6). Katz, Brown and Kim (2016) relied on the model to "expand teachers' repertoire of effective instructional blended technology tools" (p. 211). Katz et al. found that the model enabled teachers to shift from teacher- to student-centred learning. Likewise, our findings pointed to a similar shift in teachers' practice. However, the flipped model is merely one type of tool that may produce such a shift. As Estes, Ingram and Liu (2014) argued, "while flipping holds promise for helping students achieve meaningful learning outcomes, and for helping instructors make more efficient use of class time, it is but one of many instructional strategies" (p. 1).

We also saw evidence from our findings that AR tools such as research questions and data collection and analysis techniques helped teachers develop what Cochran-Smith and Lytle (2009) referred to as an inquiry stance, i.e., a "process of raising questions and using the data of practice to investigate those questions critically and collaboratively." What Cochran-Smith and Lytle (1990) described as "systematic, intentional studies by teachers of their own classroom practice" (p. 2) requires tools as a means to study their practice but, also, to act on the findings of those studies. If, as Cochran-Smith (2011) argued, "learning to teach really never does end" (p. 22), then teachers need to constantly identify new tools appropriate for inquiry. In general, as Avalos (2011) concluded in a review of the effectiveness of teacher professional development, combinations of tools may be needed for effective teacher learning.

Just as the flipped model is merely one tool that professionals can use to free up time, so too is AR merely one type of model of professional learning. An example of another model is that of *developmental work research* (DWR). DWR is a "methodology for simultaneous research and innovation in workplace settings" (Nuttall, 2013, p. 201). It has also been described as "an interventionist approach to the study of transformations and learning in work, technology and organizations" (Engeström, 2005, p. 9). The DWR cycle is similar to that of AR and involves questioning, historical and empirical analyses, modelling the new solution, examining the new model, implementing the new model, reflecting on the process and consolidating the new practice (Engeström, 2001). It is beyond the scope of this paper to describe in detail other models but a number of these exist such as *The Instructional Rounds Professional Learning Model* (Deluca, Klinger, Pyper & Woods, 2015), *Lesson Study* (e.g., Gutierez, 2015) and the *Professional Learning Communities Model* (e.g., Eaker & Dufour, 2015).

This study featured a CHAT analysis in only one context with two teachers. Their experiences cannot be generalised to other contexts. However, their experiences can serve as examples that others may implement in their own context. As well, it was beyond the scope of the study to focus on students' learning. What we know is that the teachers achieved the object of meaningful hands-on learning. There is evidence in the literature that correlates this form of learning with positive student outcomes (see Jonassen, 1999).

In this study, the application of CHAT was limited to post-project analysis. CHAT can also be relied on to direct interventions in professional practice. For example, Meyers (2007) relied on CHAT to plan and implement change in the professional practice of high-school librarians. Meyers' study involved identifying and analysing contradictions and subsequently designing a work-place intervention to resolve the contradictions. Meyers' study is one of many examples of how CHAT can guide interventions in professional practice. Use of CHAT as an intervention gives practitioners an opportunity to do what Engeström (1987) referred to as making "visible" and pushing forward the contradictions of the activity under scrutiny (p. 13). CHAT is a complex theory with a long history and application of use in diverse contexts with multiple approaches.

The teachers in this project achieved the object and changed their practice. However, we do not know if this new form of their practice is sustainable for these teachers beyond the research study. Edwards and Burns (2016) emphasised the importance of knowing if AR "impacts are sustained over time, thereby becoming embedded in teachers' professional learning" (p. 2). They also observed the lack of research on "factors that help sustain the benefits once an AR programme or course has been completed" (p. 2). We do not know if the professional learning that took place in this study would be feasible in other contexts, with other content areas and grades without the support that came from the University including the release time. Guskey (2014) cautioned "even the best professional learning experiences will be ineffective if teachers don't have the time...". In contexts where release time may not be available, as Guskey argued, school administrators may be able to free up time within the school.

The feasibility and sustainability of the form of professional learning we analysed in this paper may depend on an ability and willingness to expand conceptions of what the practice of teaching means. Socially, historically and culturally, the practice of teaching has involved content transmission. In this context, teachers' practice expanded to include designing and redesigning learning through an iterative, analytical, carefully planned and implemented, collaborative process. Conceiving of practice in this way means that professional learning for generalist teachers of science, and for teachers in other areas, must be embedded and situated in the practice itself. Situated learning perspectives have long been advocated in the research literature (e.g., Lave & Wenger, 1991). The notion of teaching practice as a process of design and redesign has gained considerable attention in the educational technology literature. For example, Voogt, McKenney, Kali and Sagy (2014) investigated how teachers learned design technology-enhanced activities in "design partnerships" with researchers.

Another important component of teachers' learning in this context was the object. The teachers had a clearly defined object and plans to meet that object. As Guskey (2014) argued, often, professional learning may be lacking in this object:

> For decades, schools have implemented professional learning not knowing exactly what they hoped to accomplish.... Without a specific purpose to guide their experiences, they often fall prey to clever consultants and adept entrepreneurs more concerned with what sells than with what works to improve student learning. (pp. 10-11)

CHAT's preoccupation with the object focuses attention, not simply on how we act, but why. It also focuses attention on identifying why that object might not be achievable in a given context. The study reported on in this paper was limited to use of CHAT to analyse the activity system of Fran and Patricia during one cycle of AR. CHAT can be used in subsequent cycles of the broader AR program to direct, as well as analyse, activity. Given the paucity of studies combining AR and CHAT, it appears that CHAT's value has yet to be broadly recognised. This paper provides a contribution towards this recognition.

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