Teacher and student reflections on ICT-rich science inquiry

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Abstract

Background. Inquiry learning in science provides authentic and relevant contexts in which students can create knowledge to solve problems, make decisions and find solutions to issues in today's world. The use of electronic networks can facilitate this interaction, dialogue and sharing, and adds a new dimension to classroom pedagogy.

Purpose. This is a report of teacher and student reflections on some of the tensions, reconciliations and feelings they experienced as they worked together to engage in inquiry learning. The study sought to find out how networked ICT use might offer new and different ways for students to engage with, explore and communicate science ideas within inquiry.

Sample. This project developed case studies with six science teachers of year nine and ten students, with an average age of 13 and 14 years in three New Zealand high schools. Teacher participants in the project had varying levels of understanding and experience with inquiry learning in science. Teacher knowledge and experience with ICT was equally diverse.

Design and Methods. Teachers and researchers developed initially in a joint workshop a shared understanding of inquiry, and how this could be enacted. During implementation, the researchers observed the inquiry projects in the classrooms and then, together with the teachers, reviewed and analysed the data that had been collected.

Results. At the beginning of the project some of the teachers and students were tentative: inquiry based teaching supported by ICT meant initially that the teachers were hesitant in letting go some of the control they felt they had over students learning, and the students felt insecure in adopting some responsibility for their own learning. Over time a sense of trust and ease developed and this 'control of learning' balance moved from what was traditionally accepted, but not without modifications and reservations.

Conclusions. There is no clear pathway to follow in moving toward ICT supported science inquiry in secondary schools. The experience of the teacher, the funds of knowledge the students bring to the classroom, the level of technological availability in the school and the ability of the students are all variables which determine the nature of the experience.

Keywords: science education, inquiry learning, ICT networks, science teaching

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Introduction

Learning in the twenty-first century needs to support students by providing authentic and relevant contexts in which knowledge is created and used to solve problems, in order to make decisions and find solutions to issues in today's world. Many science curricula aim at providing opportunities for students learning about the nature of scientific inquiry and how science is created and used, how science works and how to do science (ACARA, 2010; Ministry of Education, 2007).

Scientific inquiry is embedded in notions of social constructivism (Tseng, Tuan, & Chin, 2013) in its emphasis on interaction, communication, discussion and argumentation (Keys & Bryan, 2001) and the use of evidence, logic, and imagination in developing explanations (American Association for the Advancement of Science, 1993). It is the unpredictable and holistic process of creative development of ideas within a community of learners (Scardamalia & Bereiter, 1991) and is about moving students' thinking forward through specific forms of talk (Luft, Bell & Gess-Newsome, 2008). Inquiry learning in science is based on the idea that students benefit from opportunities to investigate their own questions about science-based topics and issues. Inquiry approaches are said to encourage more active learning, which in turn is more likely to increase conceptual understanding than are passive strategies (Minner, Levy & Century, 2010). Inquiry based active learning has been described to increase the likelihood that young people develop the attitude and enthusiasm needed for lifelong learning in science (Feldman et al., 2000; Tytler et al., 2008; Bolstad & Hipkins, 2008). On the same token the increase of e-networks that facilitate accessing information and the analysing, processing and sharing of information is said to transform learning in general and impact beneficially on 21st century science learners (Linn, Clark & Slotta, 2003). However, the range of inquiry approaches (from open to closed) means that it is left to the teacher to determine how far and in what direction to take the inquiry approach to then negotiate, implement and reflect on how it worked. Subsequently inquiry learning in science in classrooms will take on very different forms (Crawford, 2007).

The intentions of inquiry learning align with the urgent educational arguments that 21st Century science needs to be made relevant and authentic so that students find meaningful connections to this subject (Roth, 2008). This intention is expressed in many contemporary science curricula where they emphasise that school science should attempt at portraying how 'real-science' is done. It is argued that there is a need for school science to include inquiry learning, in an attempt to give learners the opportunity to investigate the way scientists explore natural phenomena and advance science knowledge, and also comprehend how the scientific community shares and validates this knowledge (Fensham, 2004; Tseng, Tuan, & Chin, 2013). Open-ended inquiry attempts to mirror 'real' scientific investigations and explanations, and also provides a framework for developing the understanding of why science needs empirical evidence (Duschl et al., 2007), while closed inquiries are teacher selected and directed problem scenarios providing a lot more scaffolds to students but less opportunity for students taking ownership (Keys & Bryan, 2001; Bell, Smetana & Binns, 2005). Depending on the nature of their inquiry, students then have opportunities to gather and make sense of data and information, to construct their own explanations, and to communicate their findings to others (Lee, Linn, Varma & Lui., 2010; Duschl, Schweingruber & Shouse, 2007). The ideal outcome from inquiry based learning is that, through this style of active investigation students will develop a level of expertise and confidence in independent and critical thinking, yet this requires sophisticated support from teachers (Renken, Pfeffer, Otrel-Cass, Girault & Chiocariello, 2016).

The challenges

It is claimed that students who undertake their own investigations take more ownership over their learning and so also discover how to learn (Hipkins, 2006 citing Bryce & Withers, 2003). In this way, the intention of using inquiry as a pedagogical strategy may go some way to address criticisms that school science can lack authenticity (Roth, van Eijck, Reis & Hsu, 2008) and address declining student interest in science (Bolstad & Hipkins, 2008; Aikenhead, 2005). While the idea of imparting students with more responsibility through inquiry is an enticing one, it also creates challenges especially if students haven't been used to this kind of learning style, are struggling with their new roles as learners or don't know how to collaborate in groups (Anderson, 2002).

Student inquiry can provide opportunities for students to connect with real-world science and technology issues that are of interest to them and they find personally engaging (Fensham, 2006) but teaching for inquiry requires a careful balance in providing students with scaffolds and models to support their investigations with nurturing independent thinking (Goldman, Pea, Barron, & Derry, 2007). Collaboration, co-construction and confirmation of ideas is appropriate and valued in science inquiry and can help achieve this balance, but these activities tend to contrast with ways of working found in conventional classrooms. These activities require more student freedom and the capacity to pose and meaningfully pursue questions of their own design.

Teachers can find the provision of support for students' scientific inquiry activities challenging for a number of reasons (Anderson, 2002). Inquiry teaching demands high levels of pedagogical content knowledge (Crawford, 2000). Teachers need to be instructed in teaching constructively and may not have access to in–service training and they may feel uncomfortable in their new roles. Sometimes they have prior arrangements such as having to use textbooks that are prescriptive or need to follow up on assessment formats that may dictate coverage of predefined content and concept areas. Parents are not always supportive, teachers may experience a lack of resources so that in the end they may feel safer, just as their students, by turning their focus to textbooks and assessment requirements (Anderson, 2002).

Researchers have found that science teachers, in supporting and facilitating learner-investigators, require different pedagogical expertise and skills, such as challenging student thinking, prompting suitable processes and declarative knowledge, guiding discussions on findings and procedures (Hackling, 2000; Haigh, 2001). That is, it demands from a teacher a sophisticated spectrum of science content knowledge paired with advanced pedagogical insights. The complexity of successful inquiry instruction was illustrated in an extensive study conducted by Lee et al. (2010), where teachers with more experience in inquiry learning produced better student outcomes. Students pursuing their inquiries may need to go beyond the confines of the physical classroom, to venture into virtual communication environments, which again brings considerable demands for teachers and their students.

Participation that allows for teachers and students to make use of social media adds a new dimension to interaction, dialogue and sharing (Mc Loughlin & Lee, 2007). Many schools provide for networked environments, for example through Learning Management Systems, blogs or e-mails where teachers and students are able to share information and communicate in a virtual space. Students may be in contact with teachers, peers, experts, or students from other schools and while this is not a new idea per se, successful communication around science projects is reportedly hard to achieve due to students' lack of experience in reflective written conversations. For example, students only rarely give or receive questions or feedback when ideas are being posted on their blogs (Feldman et al., 2000; Linn, Clark & Slotta, 2003). While students pretend to be experts when they present findings they are also in the habit of falling back into a novice role when they receive feedback from others and so a mentoring process for reflective discourse may stimulate critical student thinking and identity with the topics studied (Feldman et al., 2000). In addition to written forms of electronic communication, old and new technologies such as digital photos, videos, soundfiles or information captured through dataloggers may facilitate multimodal ways exchanging ideas. Lee et al. (2010) who conducted a study of how technology enhanced science inquiry impacts on science learning, for example highlights that further investigations are needed to explore the benefits of technology-enhanced teaching and learning including the use of interactive visualizations and more specifically how visualisations impact on learning.

Teacher use of e-networked tools has been promoted as a way to facilitate the development of collaborative and independent inquiry skills. Appropriate and meaningful integration of e-networked tools into student learning activities has resulted in richer and deeper forms of interaction, dialogue and sharing of ideas amongst students and between teachers and students (McLoughlin & Lee, 2007). However, an understanding of the affordances of software tools by teachers is imperative in exploiting them to benefit learning (Rogers & Twidle, 2013).

In this paper, we use the term ICT to refer to the use of emails, blogs, shared online forums and similar tools that allow students to access, share and exchange information. These tools are said to not only provide students with increased opportunities to interact with teachers, peers, experts, and students from other schools but that they can also contribute to a shift in the power relationships between teachers and students (McCrory, Kupperman, Krajcik & Soloway, 2000). We were interested to explore whether and how they can allow students to exercise agency in accessing and selecting information and even in the creating of their own content (Erstad, 2005; Morgan, Williamson, Lee, & Facer, 2007).

The Research

This article is based on the findings from a two year Teaching and Learning Research Initiative (TLRI) funded research project: ‘Networked Inquiry Learning in Secondary Science’ (NILSS). The aim of the project was to explore the nature of science inquiry in the development of knowledge which was socially constructed by teachers and students when interacting and supported through ICT (Williams, Cowie, Khoo, Saunders, Taylor & Otrel-Cass, 2013a).

The project built on studies into assessment, culturally responsive pedagogy and the contribution of ICT in primary science classrooms (Cowie, Moreland & Otrel-Cass, 2013; Otrel-Cass, Cowie & Khoo, 2011). This project developed case studies with six science teachers of year nine and ten students, with an average age of 13 and 14 years in three New Zealand high schools. Teacher participants in the project were all trained science teachers who had at least three years of teaching experience, and varying levels of understanding and experience with inquiry learning in science. Their experiences with inquiry learning ranged from being a mentor for other teachers in inquiry learning to those who had a basic understanding of the concept but never applied it. Their knowledge and experience with ICT was equally diverse, but all teachers were keen to develop further their understandings about inquiry in science when supported by ICT. The project was organised in a way that teachers and researchers regular came together in workshop style meetings where they presented to each other and worked out a shared understanding on the various ideas and experiences they observed. At the start of the project, teachers and researchers spent time together during a one day workshop, to develop a shared understanding of what inquiry learning means, and how this could be enacted. Previous research indicated that having a vision for learning and the necessary content is an important prerequisite to supporting student investigations (Feldman et al., 2000).

In this first workshop, inquiry learning in science was presented theoretically (Bolstad & Hipkins, 2008; Schauble, Glaser, Duschl, Schulze, & John, 1995; Tytler et al., 2008) and then discussed. We agreed that inquiry learning is a teaching approach that allows young people to draw on their personal experiences and that this could lead to students having increased ownership over their learning. This would also mean that students could take responsibility for their learning and that with perseverance they could become experts in their fields of interest. We discussed that inquiry learning is not content specific but rather framed by content and may go across different learning areas. Inquiry learning was considered a process that both involves looking for solutions to problems and required these to be backed up by evidence. Further, it may demand that students take action or present their insights to different audiences. We anticipated that it would lead to increased student motivation and confidence in being able to ask questions and that this approach required teacher enthusiasm.

The researchers observed the inquiry projects in the classrooms and then, together with the teachers, reviewed and analysed the data that had been collected. Data produced and collected by teachers and researchers included:

- teacher planning documents;
- field notes, photographs and video recordings derived from classroom observations;
- transcripts from the classroom dialogue;
- student work, including presentations, websites, movies, posters and email conversations;
- online records from networked activities (e.g. blogs);
- teacher / researcher workshop discussions, recorded and included in the analysis, and
- reflections and insights from both teachers and students. Teachers were interviewed after each observation, and documented their reflections in on online blog. Longer interviews were conducted with teachers at the end of each inquiry project. Four or five focus groups of 3-5 students from each class were interviewed toward the end of each project, to seek their reflections of the educational experience.

The following aspects of scientific inquiry, derived from the NSES (NRC, 1996, 2000) served as an underpinning framework for data analysis:

1. Scientific inquiry involves asking and answering a question and comparing the answer with what scientists already know about the world.
2. Data analyses are directed by questions of interest, involve representation of data in meaningful ways, and involve the development of patterns and explanations that are logically consistent.
3. Investigations have multiple purposes and use multiple methods.
4. Scientists formulate and test their explanations by examining evidence, and they suggest alternative explanations.
5. Scientists often work in teams with different individuals contributing different ideas.
6. Creativity is found in all aspects of scientific work.
7. Scientists make the results of their investigations public.

This data provided rich detailed descriptions of how the process of using e-networked tools to support inquiry in science evolves. An interpretative research paradigm was used, and while acknowledging the epistemological subjectivity of this approach, it also reflected the position that the participants are the experts of their own attitudes and that the context can best be understood from their position. Initial familiarization and first level of analysis of the data by both the researchers and participants was done through the Google Groups notes and workshops which involved all participants. This ensured that records could be tracked, and aided in preserving the credibility of the project (Guba & Lincoln, 1994). An inductive approach was used to derive initial themes from the data (Merriam, 2002). This thematic framework provided a structure for coding the data during the next level of analysis. The themes were then re-examined and reorganized progressively over time to reflect additional data as it was collected. This joint meaning making by all the research participants was organized through the online discussions and the face to face workshops. Ongoing analysis was enhanced by the use of the Nvivo software package which facilitated the integration of transcripts, reports, interview and video data. The themes that finally resulted from this analysis provided the structure for the organization of this article.

In this article the specific focus is on the themes that developed from the reflections of the teachers and their students as a result of their involvement in this project. While the project is about ICT supported inquiry learning, the participants' experiences are multifaceted, involving different factors which determined the nature of the journey: teacher pedagogical experience, student ability, technological availability and teacher and student perceptions. This results in the following broad ranging discussion of how teachers approached their planning and facilitation of inquiry and how students viewed their experiences in the classroom. Engagement of teachers and students in the journey, the influences on their approaches to ICT supported inquiry and the significant and common reflections that resulted from both teachers and students experiences are discussed.

Findings and Discussion

The teachers' reflections

Early conceptions

Initial team meetings between teachers and researchers revealed the teachers to be cautious in their approach toward inquiry, yet enthusiastic to develop their pedagogy and repertoire as a result of their involvement in the project. When asked about their experience in these areas, two of the teachers had previously integrated ICT in their teaching, one teacher was familiar with inquiry-based science learning, and others expressed their disquiet with using unfamiliar technology.

From the first teacher-researcher meeting, theory-based understandings of teaching and learning using an inquiry approach in conjunction with the affordances of ICT were developed in discussion. Summaries of the discussions were documented and notes of initial observations of the teachers' lessons were shared.

The discussion of the use of networked ICT to facilitate an inquiry approach highlighted a focus beyond simply sharing information, to a consideration of developing thinking and affording opportunities for communication. Some of the teachers were already using blogs, Google docs, wikis, Moodle and Three Clicks with their classes.

Although the teachers indicated that they were supportive of the valuable outcomes of inquiry learning, specific difficulties anticipated by some of the less inquiry-experienced teachers at this stage of the project included expectations from the school management in relation to the completion of the core curriculum content in preparation for summative assessments. There was a feeling amongst some of the teachers that ICt supported inquiry would take more time than traditional teaching.

> *… inquiry takes quite some time to do; it's not something that can be done in a lesson, it's something that really needs to be built (Teacher B).*

Some teachers also expressed apprehension about the level of student preparedness for implementing and conducting inquiry, and their own abandoning of familiar teaching methods and trialling new pedagogies. Researcher's initial observations of classroom teaching confirmed this apprehension by noting that some teachers were more comfortable with content-driven teaching, and in presenting a 'safe lesson' that could still proceed in the case of a technology malfunction. In the early stages of the study, student sharing of knowledge and skills was commonly observed, but this was generally teacher initiated as opposed to student initiated.

Throughout the project, each teacher was supported and encouraged by a network including one or more researchers, a teacher-colleague at the same school and a 'critical friend' teacher at one of the other project schools. Through collaboration this support network was subsequently able to explore options, offer relevant ICT suggestions, and share lesson planning templates, content and resources.

The teachers expressed that they felt comfortable sharing and seeking direction within the network as this example shows from a Skype critical friend conversation:

> *I haven't really thought of anything I'm going to do for inquiry yet …, I think I'll be asking for some help tomorrow at the meeting about how I can actually go about some of these things (Teacher A).*

Ideas were shared amongst teachers, both at school and between schools. The aim was for teachers to explore options in approaching various inquiry topics, reflect on their ICT experiences in the classroom and develop planning appropriate for inquiry learning in science. For example two teachers were talking on Skype:

> *we're incorporating three units [and] we've got probably an overarching idea, energy is all around us [so] we're just going to do the basics, just to make sure they've got the basic scientific information and then we're going to go from there (Teacher A and B in Skype Interview 1).*

The early conceptions and initial ideas of the teachers about ICT supported science inquiry continued to be developed and adapted throughout the project through exploration and discussion. Although some teachers found planning and implementing ICT supported inquiry learning a challenge, they were encouraged to begin with both topics and e-networks with which they were familiar.

In the second year as teachers reflected on the successes and failures of the first year, the whole team sustained their development of inquiry understandings, resulting in common areas of growth as they implemented ICT supported inquiry. These areas of growth will be discussed below.

Challenges and adjustments

All teachers found that challenges emerged throughout the project, necessitating adjustments and adaptations to their roles in enabling an inquiry learning approach supported through ICT. The most significant challenges some teachers had to deal with were related to relinquishing control and embracing novel roles, planning for inquiry and the need for scaffolding, implementing supportive technologies, and conflicts of interest related to school management requirements. Each of these challenges and adaptations will be discussed below.

Letting go and embracing a new role

The concerned teachers recognised that their anxiety was associated with relinquishing control of students' learning, one expressing in a meeting early in the project that he was "finding it hard to let go" (Teacher C). Developing their new roles associated with inquiry learning involved a reconceptualization for most of the teachers in the project.

> *… when I first started I don't think I realised quite how big a step a teacher needs to take back in order to allow inquiry to happen. I think it's really easy as a teacher to dictate what's going to happen in a classroom and I think the biggest thing I [have] learnt is that in order for real inquiry to happen a teacher needs to be, not removed from the situation but needs to play almost a secondary sort of a role (Teacher A).*

The teachers reflected on this at a later stage of the project in reviewing how they had developed and dealt with these dilemmas over the course of the project. The one teacher in the project who had used inquiry approaches in the past was more comfortable with 'letting go'. The students in her class displayed confidence to develop their ideas more independently in inquiry learning lessons. Other teachers were encouraged by incidents in the classroom where the inquiry approach generated student thinking and learning, evidenced by student engagement and responses, as shown in this discussion:

> *… where by projecting [the virtual discussion wall] onto the whiteboard during class allowed an instantaneous response to any questions and comments, almost competitive as the students strived to prove each other wrong. From this I noted the students were quickly taken away from their 'teacher pleasing' roles to that of being the expert amongst their peers. During these times the learning was very evident (Teacher D).*

The teachers felt that the need to relinquish some control was also directly related to the students' competencies and skill preparedness for inquiry learning, as will be discussed in the subsequent sections. Some teachers found that the fear of 'letting go' could initially be surmounted by "developing and setting the framework and approximate path that the inquiry should follow" (Teacher D) and taking on a new role as supporter, guide and 'scaffolder'. Teachers also found that in order to succeed in an inquiry approach to learning, they needed to build strong relationships with, and take an interest in their students. This was developed by creating a classroom environment where students were encouraged to share their funds of knowledge.

Planning for inquiry

As teachers commenced their inquiry lessons, they implemented a range of activities and strategies. The challenge of planning for unpredictable events and uncertain outcomes became more apparent:

> *… because you're not sure what direction it's going to go… planning for what you expect but also trying to anticipate some of those unexpected… directions that the students might take (Teacher E).*

Some teachers trialled the provision of a variety of resources "because you need to be able to support them… or have the resources that they want to have available to be able to do that" (Teacher E). In a conversation with her critical-friend, one teacher expressed the complexity of inquiry learning:

> *… open enquiry is fairly demanding in terms of teaching, it's not the stand in front of the class, do the traditional teaching, but in terms of managing resources and different students needing different things and different levels of assistance and all sorts of things so it's actually quite challenging or can be quite challenging from that perspective plus that unknown in terms of the planning – how does it fit, how long is an open ended enquiry going to take, those sorts of things* (Teacher E in Teacher E and B Skype Interview).

Planning for ICT- supported science inquiry proved to be quite different from a structured teacher-led format that was the norm for some teachers. Planning was multi-dimensional and included the consideration of group dynamics, individual student roles within groups, level of student skills, teacher preparation for well-resourced lessons and preparation of alternative resources in the event that the technology failed or was not available. Providing for a variety of group dynamics and student abilities within a class was found to be a significant factor in planning and executing inquiry learning. Teacher F noted that the more able students "… take the freedom and they go with it and it's almost like an excuse to engage".

However, the less-able students required more monitoring and guidance, and teachers found that "it's actually very busy teaching in a low-level inquiry lesson" (Teacher D). Where students were of lower ability there were frequently reported high levels of disengagement. Engaging reluctant learners became an important planning and implementation factor in inquiry learning:

> *In those lower groups with their lower levels of literacy things it can be … like they'd need more support and you need like, some clones in the room to keep everybody on task and to keep them focused (*Teacher E in Teacher E and B Skype Interview*).*

The need for scaffolding and developing skills

Early in this project as teachers were becoming familiar with inquiry learning, some developed a sequence of activities on a topic to be presented over a period of time in order to scaffold student learning. Scaffolding was also seen as laying a foundation of short simple activities, followed by more open-ended and complex activities where the student is given more choice and decision making options. For example, one teacher scaffolded by first providing a simple investigation for students to do, followed by an example of an open-ended investigation designed by another group of students, and finally required the students to design their own inquiry investigation.

In classes where student competencies and skills were more variable, teachers found it useful to give focused support, enabling students to work collaboratively with others and so assist each other in advancing their thinking. Teachers also found that they were required to scaffold more at some stages of the inquiry process than at other stages. The following quotations demonstrate the ways different teachers used scaffolding approaches to develop science specific vocabulary.

> *I've started a physics [topic]. I've just been focusing on the scaffolding of some of the themes behind it; and then I'll get to the stage where I'm going to [focus on] a concept and we'll go from there as far as the inquiry portion goes. But I just found that my kids weren't up to a level that I felt comfortable with letting them go. So … yeah, I sort of scaffolded them a lot more than perhaps I would have liked to (Teacher C, in Teacher C and D Skype Interview).*

Students also required guidance in developing skills such as information searching and analysis.

> *They [the students] find it difficult to get information out of the text, whether it's online text or written text. We've done a few introductory activities that are just about extracting information [to] get them upping that skill (Teacher F).*

Technological benefits and challenges

Teachers began the project using information technologies with which they were familiar and comfortable, but over time attempted using different and varying technologies. In the first year of the project, researchers supported teachers with their use of ICT, such as Wallwisher to answer initial questions in a brainstorm session, or Moodle as a record of the development of group discussions. In the second year, a lesser amount of such support was necessary and teachers enabled students to use technologies to develop real e-networks in more advanced ways, for example to communicate ideas with a class at a different school, or embedding video in their presentations.

Being part of the project has made me do things that I probably wouldn't have done … in terms of using online technology and … putting in things like getting them [to] video … some of that stuff I probably would have said was in the too-hard basket. (Teacher E)

The students were frequently more familiar with some information technologies than the teachers. In this inquiry context, where students had more control over their learning than in traditional classrooms, it seemed natural for the teachers to depend on the students technological expertise, and consequently, the students demonstrated increased enthusiasm for involvement and were more inclined to be motivated and engaged when using technology in which their expertise was recognized.

You could tell that the boys had been onto iMovie and done editing before, whereas some of the girls hadn't. The best thing about that was… I mean I've never even opened iMovie, so they couldn't ask me how to do it, they had to ask each other (Teacher B).

Access to online resources from home was easy for this cohort, their knowledge of online applications was high (Teacher D).

For a number of teachers, the challenges in the use of e-networks included the constraints of school digital server limits or unreliable performance. This gave rise to times the teachers required alternatives to e-network dependent tasks, and they had to provide students some options for the continuation of their inquiry. One positive case arising from malfunctioning technology was a decision to let students use their mobile phones in class, a decision which worked so well that it became a regular feature.

We've had a real struggle this year with the school network. The proxy server has died a number of times, you go to do something and you can't. Or like when we went to do posters, we had problems with administrative blockage at school and even when we got that [fixed] a couple of times later when you go back to use it, it's been reinstated (Teacher E).

They are using the technologies on their cells [mobiles] to record it, so they are going to the next step themselves… I'm certainly not going to stop them (Teacher D).

Conflicts of interest: time and assessments

Teachers understood, through experience, the time it would take to convey information in a transmissive mode to students, but were unfamiliar with the amount of time required for an interactive pedagogy like inquiry learning. This resulted in tension between adhering to a scheduled plan and the less predictable reality of time required to cover curriculum content using this inquiry approach.

And it's difficult; I think it's partly the secondary timetabling, because you know you have such a limited timeframe it's difficult to open up that inquiry sometimes and let them sort of loose, as it were, because you've got to be mindful of those time restrictions and things (Teacher E).

In addition, some teachers found that they had to change their approach to scaffold foundational concepts before students could progress with a scientific inquiry, and this further extended the amount of time required for inquiry. It was discovered that without sound foundational concepts, and appropriate scientific language, students found it difficult to develop appropriate inquiry questions and initiatives for their own learning.

The constraints around school requirements to achieve a set of outcomes and prepare for assessment was a real concern in the implementation of e-networked inquiry learning. Teachers found it challenging to connect students interests with what the curriculum indicated they should be learning in school, and aligning this with school-required assessment, as the assessments were largely "knowledge-based [instead of] skills-based" (Teacher A) assessments.

> *We didn't get through as much as we thought we would - when the kids were doing the inquiry, time sort of elongates - what you think will take a lesson or two takes three or four and then you have to accommodate that somewhere else in terms of what else is a requirement to do and what you can afford to sort of leave out while they're exploring. So there is certainly a time issue with it (Teacher E).*

Schools required students to complete standard tests, and if they didn't, teachers were unable to acknowledge the students' efforts with marks in their school reports. One teacher expressed how conflicted he felt between the traditional curriculum requirements and inquiry learning:

> *Learning is so limited, that sort of rote learning that they can do, whereas if I give them [something] they have to explore or find out for themselves, each person in that classroom found out something completely different. No one knows exactly the same thing as what the next person did. And I think that creates issues in itself in that how do you assess that? (Teacher A).*

Towards the end of the project teachers were asked to reflect on their experiences, what they had learnt, what worked for them and whether or not they would continue to use the e-networking tools and inquiry teaching models they had developed during the project. With respect to ICT, one teacher felt that she was becoming confident and comfortable with using the technology:

> *I felt that we were just starting to really try and enter that idea of networking and the fact that because I'm not that familiar with some of those other options I probably haven't been thinking about how to weave those into the planning (Teacher E).*

Most of the teachers commented on the benefits that ICT- supported inquiry learning had for the students, but emphasised that it should not be a forced methodology, but a means to have students 'buy into' their own learning. The teachers felt that in order for inquiry to be successful they had to develop an attentiveness to students' interests, encourage foundational ideas (funds of knowledge) that students bring into the class, and develop links between school and community projects that add meaning to their learning.

Teachers referred to inquiry learning as "*another tool in the box*" that *"invigorates my teaching"* and something that they had enjoyed. However they were not convinced to only use this one method, because "*if you did enquiry all year the kids would get bored of it*" and although they felt that inquiry can effectively be implemented in high ability classes, the lower ability students had more difficulties. The dynamics of the lower ability classes, and the issues of attentiveness, lower levels of literacy and regular absenteeism meant that the implementation of an inquiry approach was "*almost … too difficult*". The level of scaffolding required left little time and space for individually developed inquiry approaches to their own learning.

Another teacher summed up his enthusiasm for networked inquiry learning by referring to the conflict he felt about what he and his students had gained in the project in his classroom:

> *It's just sad that we live in a world driven by assessment and not driven by learning (Teacher A).*

Teachers acknowledged that a highlight for them was witnessing their students sharing their ideas and working in groups to develop their own learning. Once students were given guidelines for working in groups, they were able to "understand the active roles they can take on in collaborative group work" (Teacher B).

In addition, teachers recognised how ICT supported inquiry learning was an ideal vehicle in developing skills, specifically related to the key competencies as presented in the New Zealand curriculum (Ministry of Education, 2007)

> *the key competencies … match up with inquiry beautifully … participating and contributing, thinking, working together, … and that's, for me, what inquiry is all about is getting [students] to work together on something that they're interested in but still meeting your obligations in terms of curriculum content (Teacher A).*

In summary, teachers discovered that they required a different range of pedagogical expertise and skills when implementing an ICT supported inquiry approach in their classroom.

The students' reflections

As with the teachers' journeys, the students revealed that they had a variety of experiences throughout this project as a result of the learning and growth in skills and understanding throughout the two years, beginning with the unease they felt at the first introduction to an inquiry task. The students' trepidation at the start, their growth, the challenges they experienced and their reflections are discussed below.

Student trepidation

Students' activities were observed and their discussions and interviews analysed to reveal that their approaches to e-networked inquiry learning were initially apprehensive and uncertain. Students had a variety of experiences in different schools and classrooms with their different teachers, however a number of themes were common.

In many of the initial inquiry learning lessons, it was apparent to the teachers and the researchers that students were being exposed to new experiences and there was a need for new skills. Students felt "challenged" as they were uncertain about where to begin with their learning activities and what the expectations were. With undeveloped researching skills, the students indicated that they were overwhelmed when required to search for information on the internet, preferring a list of trusted websites. One teacher said:

> *The problem is when they find so much information, what bit do they use? You type in some of those key words and Google comes up with a million and a half pages (Teacher C).*

Furthermore, not all students were familiar with ways of becoming engaged and contributing ideas, and how to consolidate ideas and information with a focus on the task at hand, when "it wasn't entirely clear, we didn't know what we had to know" (student of Teacher D). Some students recognized they did not have the self-discipline to deal with this new autonomy when they were used to being constantly monitored by the teacher. In reflecting on a learning activity, one student responded:

> *I'm not saying he [the teacher] needs to keep control of the groups more but like we kind of got really off task and maybe he needs to give us more of a growling and be like: you guys have to do your work and stuff, because I think it got a bit out of hand (Student A of Teacher D).*

The students frequently selected their own groups, with one teacher setting the proviso that if the group did not work well together it would be disbanded. As teachers provided more scaffolding and guidance, students generally showed more focus and generated appropriate ideas. Where students were inexperienced with ICT, the teachers had to allow sufficient time for familiarisation, and so develop confidence prior to producing outcomes. The students gradually became familiar with collaborating on Moodle, as this excerpt shows:

> *This was the first one [learning activity] we have done on Moodle….. When I read the question I was a bit confused, but then I read another students responses and I started to understand what we were supposed to do. The good thing about it is you don't have to repeat the same thing, you can just say you agree with that person and then add what you think (Student B of Teacher F).*

Students experienced previously unknown tools in using a range of ICT's, but seemed to display little trepidation for the new technologies. In working on one presentation with two computers at the same time (on Glogster), a student described it as a new experience, and "really cool" because they were collaboratively involved in the presentation, "we were doing it but we weren't doing it together" (Student group of Teacher A). At another school students were working together on Google Docs so they could work on the same thing at the same time, and felt that it helped them to "try and work together because it was easy to communicate and share what we have done even after school" (Student group of Teacher B). Teachers found this student adaptability to unfamiliar technology a useful quality when introducing new information technology tools.

Student growth and learning

Student growth and learning was evident in the three areas of research and collaborative skills, display of key competencies, and autonomy and creativity.

Student growth and learning was fostered by the social construction of knowledge in science inquiries, supported by parallel collaboration in both face-to-face and e-networked settings. As teachers highlighted the rationale for sharing information, namely to facilitate more effective learning (with examples from the scientific community), students were encouraged to replicate this process in the classroom by sharing resources, communicating and collaborating.

Different groups collaborated in different ways, for example some would research independently and then discuss the information; other groups would research together and assemble obtained information. Students had varied strengths, knowledge and understandings that they brought to the group and also gained additional skills through the process of collaborating. Teachers noted on a number of occasions that they were surprised by the initiative taken by some students, their level of authority displayed when given the opportunity.

> *I think working in a group helped me more, because when you don't know something then your peers will be able to help you … I reckon we developed more independent researching skills, like instead of the teacher going up in there and telling us this and that, we learned how to like find information ourselves (Student group of Teacher D).*

And from the teachers' perspective:

> *Some of the students who I've identified as being less able, once we actually get going on some of the activities, they have different skills to bring to the group, like using certain research programmes or looking up particular things or some of them definitely showed better perseverance. So they bring different skills to the group through collaboration (Teacher E).*

As students reflected on their first inquiry learning topic, they explained that they had found it challenging, but also learnt a great deal from the task, commenting:

> *it's a good starting point, this project, for learning how to do good projects on your own, especially since we didn't have much guidance by the teacher, we were sort of left to do it ourselves (Student C of Teacher B).*

Students were able to revisit their ideas during interactions in the classroom, such as listening to recorded discussions, or reviewing online text discussions they had the previous evening. Some students felt that they were better able to express their ideas verbally rather than writing them down, and became more confident as a result of this affordance. Other students were more confident in smaller groups of friends, as the freedom to share their funds of knowledge gave them opportunities to use their knowledge and skills to assist other students. Students indicated that they found it useful to access information and share ideas from home after school hours. The variety and depth in the following quotes illustrates the value of this social construction of knowledge.

> *If you communicate with other people it's a lot easier to learn….You're like interacting with other people, making your ideas and their ideas not just what you know and what you don't (Student group 1 of Teacher E).*

> *With things like the website and Google Docs we were able to collaborate … without being at school. So we could share each other's knowledge... Like before we posted on the website [we answered] questions and shared thoughts with each other before they went up onto the website (Student group 2, Teacher D).*

The teachers noted that the collaborative group work was able to continue in between classes, explaining:

> *In the use of networking, particularly the Google Presentations [and] even with the emails, it was nice to see … that the learning was continuing at home and that they're taking this stuff home and sharing it and continuing with it (Teacher A).*

Challenges along the way

Throughout this project students were required to adapt to responsible collaborative sharing roles with their peers that were novel to them, rather than answering to the teacher. One teacher noted that learning was very evident when students were able to move from their "teacher pleasing roles to that of being the expert amongst their peers" (Teacher D). When students were asked how they felt about controlling their own learning, one student replied that she felt the group had required more guidance.

> *I know myself that if I get a sheet of work and the teacher doesn't tell me to do it, I won't do it. Like I think that type of learning might be good if you're like year elevens, twelve and thirteens, but in year nine and ten you still need a bit of teachers like to push you (Student A of Teacher D).*

Students indicated, however, that technological distractions occurred within the social atmosphere of the classroom which had the potential to result in diverted attention and incomplete work. Students were able to identify that although the internet provided a useful means of communication, it also provided a means of distraction:

> *I thought the internet was good to be able to communicate between us, but I think that quite a few times we did get side tracked while, you know, like started doing random spam at each other, like when we were messaging. It was good to be able to access the information quickly but we did get side tracked a few times (Student B of Teacher B).*

Teachers agreed that some students required more monitoring, were easily distracted and required more guidance from the teacher during the inquiry collaboration tasks. Students felt that their need to learn with a degree of independence was to be balanced with teacher input and guidance. When students were asked if they preferred teacher-directed classes or having control over their own learning, they responded:

> *Maybe both…the teacher would tell you like part of it and you'd do the rest by yourself… a bit of direction from the teacher but yeah, not too much (Student group of Teacher E)*

However, at the culmination of the project, teachers agreed that one value of the e-networks in the science inquiry context was as a means to enrich students' skills in knowledge discrimination and acquisition. Technology facilitated student learning by providing tools, such as

> *flip cameras, some of the students are using their own mobile devices, whether it's as a camera or to record or as their research tool, like however they're using it so it provides a tool to facilitate the learning but I still think it's quite important that there's some scaffolding there (Teacher E in Teacher E and B Skype discussion).*

Reflections of the students

Students' reflections indicate that they felt they had developed in primarily three areas: increasing their technical skills, improving their researching skills (how to collect information) and developing their science subject matter understanding.

> *Yeah. It was good to learn like technical skills as well as the actual subject, so it benefits in that way. We probably learnt more about how to put it together than actually what we were learning about….the subject. It's more learning like how to collect information and put it together. So it probably would be easier a second time, just because you would know how to plan it (Student group of Teacher B).*

Reflecting on the role of the teacher in an inquiry approach to learning, a number of students commented on the balance of teacher input and student independence.

> *It needed teacher input as well. I think you need a bit of both. You need teachers to ... Just guide you, 'cause that's what school is about.... they're teaching it 'cause they understand it so they need to kind of guide you and then you can [use] the technology (Student group of Teacher D).*

The use of communication technologies empowered students to gain autonomy in supporting their research through ICT. In being encouraged to take ownership and responsibility, they had more input into their own learning. Even with the initial apprehension experienced by students, they discovered through collaboration and co-operation how to commence and progress an investigation rather than being provided with step by step instructions. The students responded constructively to their autonomy as enabled by ICT, which included making decisions, being organised, carrying out tasks independently and staying focussed on the inquiry task. Teachers and researchers both observed an increase in levels of motivation of the students by observing their engagement and enthusiasm for involvement in science inquiry.

> *Instead of waiting for the teacher to walk into the room, the font of all knowledge, they've got access to the world at their fingertips… They're fostering that lifelong learning (Teacher C at Team meeting)*

Students and teachers both felt that there was insufficient acknowledgement of the amount of effort put into their inquiries, because the assessment criteria were focussed on the end product content rather than the process:

> *That's hard because with my lot we did a project and they had to show it on Youtube at the end so they did all their research on the computers and we had the odd stand-alone lesson when they had some questions and then they used either the flip cameras to record it and then iMovies to do any editing. But what the videos don't show is the amount of work the kids did though, so for those two groups, the end grade didn't reflect their work (Teacher B).*

Teachers reflected that this dissonance indicated a failed reconciliation between traditional systems of content examinations and newer pedagogies related to inquiry approaches.

Merging reflections

There are elements of the experiences of both teachers and students which are common, and indicate the rich and complex pathway followed in the joint learning experience.

The beginnings of the project were tentative for both groups: the teachers were hesitant in letting go some of the control, which they associated with guidance they provided to their students and feared would be missing otherwise; and the students felt insecure in adopting some responsibility for their own learning. Over time a sense of trust developed to help ensure this 'control of learning' balance moved from what was traditionally accepted, but not without modifications and reservations. Teachers came to realize that different groups of students required different levels of scaffolding in order to progress (Hackling, 2000; Haigh, 2001), and students felt frustrated that while they had control over their own learning through the inquiry approach, they had no control over assessment, and the dissonance that developed through this inconsistency was a source of concern.

The issue of scaffolding was an essential component of the transition to inquiry learning, and involved a process of 'trial and error' in getting the balance right (Goldman, et al., 2007). There were essential skills that students required, not only related to the scientific content they needed in order to progress their inquiry, but also related to the supporting technologies the groups utilized and to the skills needed to ensure effective group dynamics. It was difficult for the teachers who were new to the inquiry process to anticipate both the conceptual and procedural essential skills needs, and consequently they could only respond when the need arose, and this resulted in some frustration from the students. The areas of essential scaffolding needs were initially confused by students who just wanted quick answers to their problems and so sought teacher advice, as perhaps they had been used to doing in the past. Teachers then needed to differentiate between elements of inquiry that should be within student capacity, and those that represented genuine scaffolding needs.

A significant imperative of this project was to support approaches to student inquiry with a range of e-networked systems involving hardware, software and cloud elements. This IT journey seemed an easier path for the students than the teachers. In all cases there were clear instances of students implementing e-support networks, either independently of the teacher or because the teacher did not have experience with the specific technology. This superior level of information technological literacy by the students facilitated the process of assuming responsibility for their own learning, and also emphasized for the hesitant teachers that students funds of knowledge were valuable, useful and so needed to be respected.

The inquiry activities implemented by teachers in this project were almost all group based, and this contrasted with teachers prior experiences where group work was the exception rather than the rule. Teachers initially underestimated the need to be explicit about the dynamics of group work, and to employ techniques such as discourse analysis (Oliveira, Boz, Broadwell & Sadler, 2014) to develop models of group learning. The consequent dysfunctional groups, although temporary, were an initial impediment to progress (Feldman et al, 2000). The need to work in groups, both in class but also outside of class, was quickly recognized by students as an opportunity for the application of communication technology to facilitate their inquiry progress.

Networks were used to cultivate and stimulate interaction and participation opportunities between the research participants, teachers and students to enable multimodal ways of teaching and learning of science inquiry. Collaborations which were supported through Moodle, Skype, Youtube, Wallwisher (now called Padlet), videos and other forms, allowed participants to examine multiple perspectives on inquiry. This provided a new space and time for sharing, thereby expanding the ways students, teachers and researchers engaged in dialogue about learning, teaching and researching (McLoughlin & Lee, 2007).

Conclusion

The representation in this article of all the teachers and students experiences across the six case studies provides a complex picture of multiple variables and a range of influences on the teachers and students experience in moving from a traditional approach to science teaching and learning to an ICT supported inquiry approach. The consideration of all these experiences has enabled us to conclude that there is no formulaic pathway to follow in moving toward ICT supported science inquiry in secondary schools. The experience of the teacher, the funds of knowledge the students bring to the classroom, the level of technological availability in the school and the ability of the students are all variables which determine the nature of the inquiry. It seems that a key requirement is flexibility: to seek alternatives when the technology does not work, to change notions of what scaffolding (both conceptual and procedural) might be necessary to ensure success, and to make curriculum and assessment adjustments to accommodate the characteristics of inquiry learning (Renken, Pfeffer, Otrel-Cass, Girault, & Chiocariello, 2016). Our findings point towards a need for more refined unpacking of the discreet aspects of inquiry learning such as the differentiation between providing students with support and answers and providing scaffolding to support meta dimension of learning. Teacher scaffolds are needed, but for inquiry to be sustainable they also need to be faded out so students can learn to take ownership and experience their work as being authentic.

It is clear that ICTs are valuable in supporting an inquiry approach to learning in science. They provide students with opportunities to review past experiments and discussions, to search, discover and analyse information from many sources, to collaborate across time and space, and to share the results of their inquiry. These affordances enable student ownership and responsibility for their learning. However, those teachers who may be lacking the sophistication with which students operate with and though technology must recognize and utilize student expertise in these areas. This is particularly important so that the complex amount of work that goes into inquiry and is supported through ICT is effective.

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