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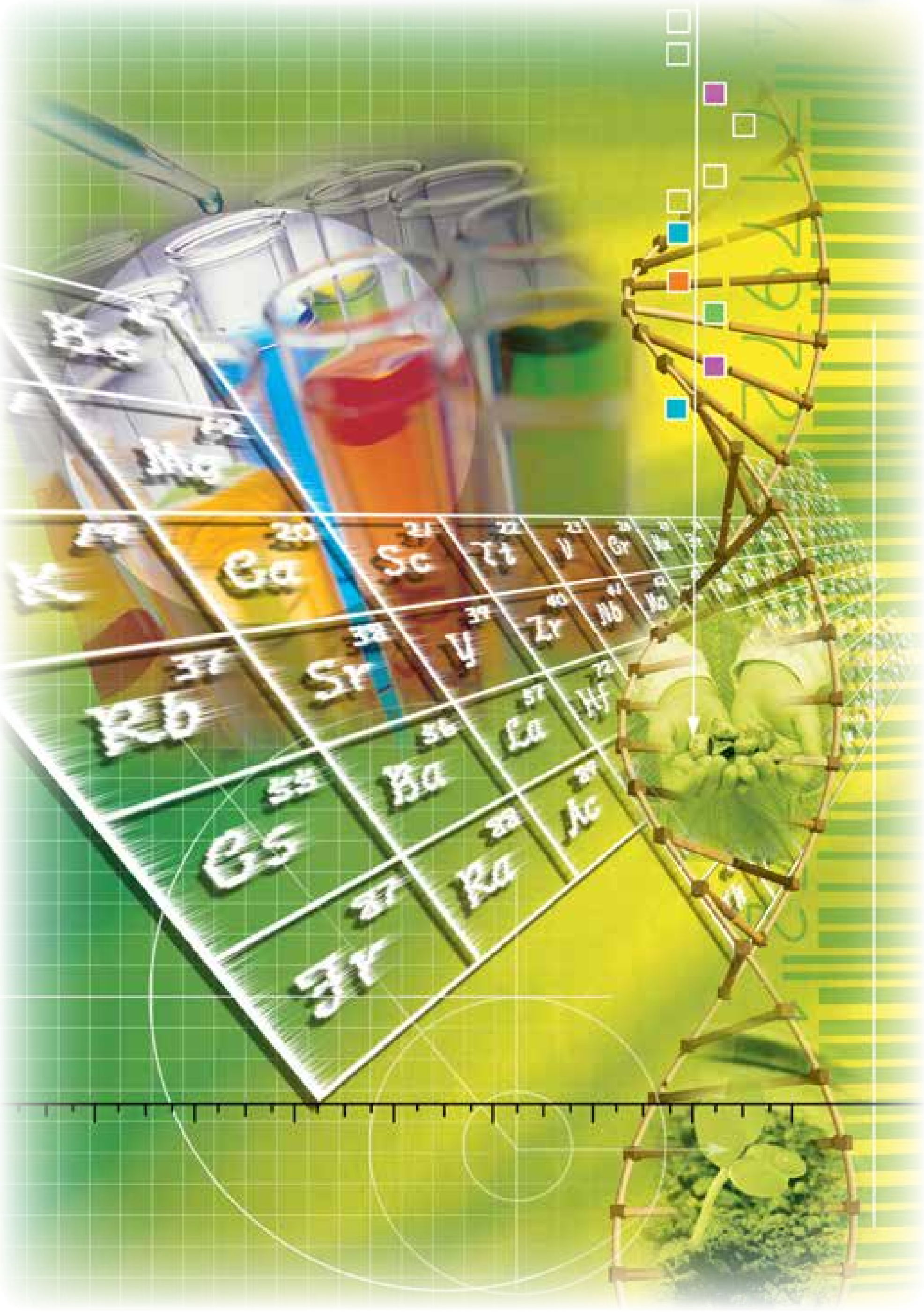

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ASEJ publishes scholarly work and strictly follows the blind review procedures and many other editorial policies described in the *Publication Manual of the American Psychological Association*, 5th edition (Washington, DC: American Psychological Association, 2001). Thus *ASEJ* is a refereed journal similar to most other scholarly periodicals published in Canada and the United States.

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Wendy Simms recently completed the learning sciences EdD program at the Werklund School of Education, University of Calgary. Her research focuses on science and sustainability education in the K–7 classroom, with a special interest in environmental identity development and citizen science. She is involved in extensive science outreach initiatives as a faculty member of Vancouver Island University (VIU) and is currently teaching a new sustainability and teacher identity course to VIU preservice teachers. As a board member and volunteer for the Nanaimo Science and Sustainability Society (NS3), she was part of an interdisciplinary team of science educators and scientists that designed a citizen science project for Grade 5 students.

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Message from the Editor

Monica M Chahal

Dear friends and colleagues, I am very excited to take this journey with you as the new editor of the *Alberta Science Education Journal*. I would like to thank the former editor, Wytze Brouwer, for his dedication and contributions to science education and his years of service in this position.

The 2017 ATA Science Council conference was earlier this month, on the theme of "Making Space for Science." As science educators we know the relevance of our subject in an ever-changing world, and we are fortunate in that we are placed at the forefront of engaging our students, in both the relevance of science and the wonder of our subject. Thus, the need to "Make Space for Science"—it is our job to put our elbows up and both literally and figuratively create space for our amazing subject. As educators, we assist our students in their journey in discovering that science is everywhere and touches everything that they do, be it in what they eat, how they play or where they work (or will work). The articles in this issue build on this notion of relevance and engagement.

For example, Jerine Pegg's article, "Teaching for Relevance in Science," is a case study of one Alberta high school science teacher's approach to making science relatable for students. It highlights various strategies that teachers can use in a typical classroom setting to increase student engagement and help students make connections between science and their lives.

Building on this notion of relevance, Kerry Rose's article, "Assessing Changes in Scientific Literacy in an Alberta Science Option Course," analyzes the impact the course had on student perception and attitudes regarding scientific literacy and the role of myth in society.

Throughout both of these articles runs a theme of the need for student-driven investigations. The four articles that follow provide in-class examples of activities that may provide a response to this theme. Wendy Simms's article, "Integrating Citizen Science into the Classroom to Support Inquiry-Based Learning," discusses how teachers are often left wondering how to implement this teaching strategy into practice. She suggests that class participation in citizen science may become an avenue to support teachers and students as classrooms begin to transition into more inquiry-based learning environments, and uses a British Columbia example as a possible template for Alberta science educators.

Much global research indicates that many students between the ages of 10 and 14 years make the decision that science studies and careers are not for them, even though they have little knowledge of what scientists actually do. Carol Rees and her team's paper, "Creating an Engaging Science Inquiry Activity for Middle School Students That Incorporates Online Remote Access to Analytical Instrumentation," describes a unique collaboration that aims to engage Grade 8 students' interests and awareness of the world of professional science through remote online lab access. The collaboration by faculty and school brought together many partners in a cross-curricular inquiry project in response to the new British Columbia curriculum. Considering the current Alberta curriculum review, this article was timed perfectly.

Building on the importance of science education for students, Hyacinth Schaeffer and Bonnie Shapiro, in "Promoting Scientific Literacy Through the Use of Adapted Primary Literature in Secondary Science," provide a rationale for the importance of developing new approaches to address the development of scientific literacy in secondary school classrooms in order to promote critical thinking in students. The context is a research project that examined the introduction of adapted primary literature during a three-year teacher professional development program. This article is of particular interest to Alberta teachers because it addresses the connection between literacy and inquiry with cross-curricular competencies. Furthermore, Schaeffer and Shapiro provide tangible examples for teachers to download.

Beaumie Kim and Reyhaneh Bastani's article, "Students as Game Designers," discusses the possibility that designing games for learning can support a transdisciplinary approach to STEAM (science, technology, engineering, arts and math) education, which helps learners think creatively, flexibly and systematically for any discipline. The pertinence of this article lies in its connection to how game design can create connections beyond mere rote memorization.

I would like to thank the many contributors to this issue, in particular the many reviewers across Canada, who gave their time to contribute to the dissemination of science pedagogical knowledge in our province. If you are interested in reviewing articles or submitting articles for future issues please contact me at atascjournaleditor@gmail.com. I would also like to provide a special thanks to Marie-Claire Shanahan, PhD, for her support and guidance throughout this process. This edition of the journal is truly a team effort!

I look forward to the year ahead were we all, with a bit of luck, will find our unique ways to make space for science through relevance, engagement and, most important, *joy*! I hope the articles in this issue help you and your students on this journey.

Monica M Chahal has been dedicated to education since she can remember. Her work at an inner-city school in Westminster, London, inspired her to want to make education more inclusive and accessible for marginalized youth. She completed her master's degree at the University of London before returning to Canada, where she received a PhD in secondary education with a focus on curriculum studies from the University of Alberta. She is currently an adjunct professor at the University of Alberta in the Faculty of Education. She understands the power and necessity of volunteer work and community involvement to effect change, and has received several awards for teaching, research and volunteer work.

Teaching for Relevance in Science

Jerine Pegg

> To ensure relevance to students as well as to societal needs, a science program must present science in a meaningful context—providing opportunities for students to explore the process of science, its applications and implications, and to examine related technological problems and issues. (Alberta Education 2007)

The statement above is found in the program rationale and philosophy on the first page of every current high school science program of studies document in Alberta. Making science relevant for students has been identified as an important goal of education since the 1800s (Hurd 1998), and statements similar to the one in the Alberta program of studies can be seen in curriculum documents and education reports since the early 1900s (Bennett 2001). Although it is clear that ensuring relevance is, and has been, an important goal of science education, what is less clear is how to do this and what this looks like in the classroom (Holbrook 2003).

There are numerous examples of specific curricula, projects and approaches that engage students in connecting science learning to real-world contexts and applications. However, the majority of these examples involve the use of specific curriculum resource materials or activities (eg, Ramsden 1997; Rutledge 2005; Siegel and Ranney 2003) or are primarily opinion pieces with teaching advice for teaching relevant science (eg, Hobson 2001; Van Aalsvoort 2004). What is lacking from the literature are detailed explorations of what teaching for relevance in science can look like in typical classroom settings. This paper provides a case study of one high school teacher's approach to making science relevant for students. It highlights various strategies that teachers can take to increase student engagement and support students to make connections between science and their lives in typical classroom settings.

Methodology

This study was conducted as part of a larger research project exploring student perceptions of the relevance of science and the impact of relevance-based instruction on student attitudes. This paper presents a pilot study of one high school teacher's approaches to making science relevant. A case study approach (Merriam 1998) was used to provide an in-depth examination of the nature of this teacher's instruction.

Context and Participant Selection

The data for this case study was collected from a high school in central Alberta. Prior to the start of data collection, the science teachers at the school were invited to a workshop in which the project was discussed and teachers were introduced to online curriculum resource materials designed to help students see how science, engineering and technology relate to their everyday life.[1] Participating teachers were asked to implement at least five lessons or activities within one unit focused on making science relevant to students' lives and told that they could use resources from the online site or their own resources for the lessons.

Two teachers initially volunteered to participate in the study; one was purposefully selected (Patton 2002) for this analysis, based on the teacher's depth of experience and richness of the context (ie, two diverse classes). The teacher selected for this case study has taught high school science for over 25 years. Two of the teacher's classes, Biology 20 IB and Science 24, were selected for observation due to the differences in curriculum and student populations represented by the two classes.

Data Collection and Analysis

Classroom observations took place over a four-month period during the second half of the school year. Nine observations were conducted in the teacher's Science 24 class and six in the Biology 20 IB class. Field notes were taken during the observations in order to document the types of lesson activities and discourse during the lessons. When possible, interviews and informal discussions with the teacher occurred to discuss the teacher's lesson planning choices. These interviews and informal discussions informed the analysis of the classroom observations.

In addition to field notes and interview/discussion data from the teacher, student interviews were conducted with four students from Biology 20 IB and three students from Science 24. Students were selected from volunteers in each class. The interviews were approximately 30 minutes long and probed student perceptions of how they saw the relationship between science and their lives. In the interviews, students were also asked about their perceptions of their current science class. The interviews were audio recorded and transcribed for further analysis.

Data analysis occurred in two stages. First, the observation field notes were reviewed and coded to identify specific instructional approaches utilized by the teacher that related to the study focus on science relevance. Second, the teacher and student interview data was reviewed in order to further explain the teacher's intentions for the instructional approaches and the students' responses to them. Drafts of the analysis were shared with the teacher as a form of member checking to verify the researcher's interpretations (Lincoln and Guba 1985).

Findings

The pattern of instruction in the teacher's classroom included teacher-led discussions, lab work, and other activities (role playing, topic research and poster creation). The observations in both the Biology 20 IB class and the Science 24 class provided insight into how this teacher approached the goal of science relevance with two different groups of students. From the observations, three key strategies were identified in the teachers' approach: (1) frequent connections to interesting and relevant examples, (2) opportunities for student engagement in discussions and (3) scaffolded opportunities for students to make connections to their own lives. In the following sections, these strategies are described in greater detail, followed by a discussion of the impact of the teacher's instructional approach on students.

Strategy 1: Frequent Connections to Real-World Examples

In both classes, the teacher made frequent connections to examples that connected the science content in the curriculum to real-world examples. Figure 1 provides examples from five different lessons showing the diversity of connections that the teacher made between the science content and relevant real-world examples of that content.

The examples that this teacher used in her lessons were not just typical examples that would be found in any curriculum—this teacher included a diverse range of examples that included examples from recent news stories, local and regional contexts, and personal experiences. It was clear from the classroom observations that the students were engaged in the discussions as evidenced by their regular contributions to the discussions, described below.

Strategy 2: Opportunities for Student Engagement in Discussions

In addition to the connections that the teacher made to examples highlighting the relevance of science, the students in both classes also regularly proposed additional connections. The classroom environment created by this teacher and specific strategies used in the classroom discussions provided opportunities for students to make connections to their own lives. Three strategies were observed in the teachers' instruction that supported students in contributing to the classroom discussions:

- **Discussion prompts that elicited engagement.** During class discussions, the teacher often asked students questions that invited them to contribute what they knew about the topic and/or connect the topic to their own lives. For example, in a Science 24 lesson on genetic engineering, the teacher began by asking the students what they knew about the topic. One student spoke about their understanding of genetic engineering, and another student stated that a "liger" (hybrid of tiger and lion) was an example of genetic engineering. This led to

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[1] Resources were from the website CurioCity (https://explorecuriocity.org/), developed by Let's Talk Science.

Examples:

Biology 20 lesson on muscles—connections made to muscle cramps, rigor mortis, Olympic sprinters vs long distance runners, dark meat and white meat in chickens, and tetanus.

Biology 20 lesson on nutrition—connections made to night blindness, personal story of when sibling ate lots of vitamin C, scurvy, how Indigenous Canadians showed shipwrecked soldiers how to get vitamin C from bark, how most Canadians are vitamin D deficient, cast iron, personal story about blood draws and low iron, how people in Alberta are low on iodine, story of students with goiters, Chernobyl, story of radio station contest that resulted in someone dying from drinking too much water.

Science 24 lesson on acids and bases—connections made to stomach acid, acid rain and relevance to Alberta and Saskatchewan, pH of blood, rust, how to protect cars, sacrificial metals. Additional connections were proposed by the students, eg, student drinking bleach.

Science 24 lesson on energy transformations—connections made to flashlights, iPods, power plants, pacemakers, hybrid cars.

Science 24 lesson on genetics—connections made to blue eyes, recent news story about artificial base pairs, Rosalind Franklin, identical vs fraternal twins, selecting the sex of children.

Figure 1. Real-world examples discussed within science lessons for Biology 20 and Science 24

a discussion about what the student knew about ligers and where the student had learned about it.

In another Science 24 lesson, on acids and bases, the teacher talked about stomach acid, which prompted a student to reveal that she had had a stomach ulcer when she was in Grade 9. The teacher then asked how many students know someone who had an ulcer. Approximately five students raised their hands. Another student said that she knew someone who tried to commit suicide by drinking bleach. By prompting the students to contribute to these discussions, the teacher maintained engagement and created the opportunity for students to connect the learning to things that were personally relevant to them.

- **Redirecting student comments to focus on science.** In the Science 24 class, students often made comments or had side conversations that were not related to the topic of the lesson. Instead of ignoring these student comments, the teacher often redirected the conversation to how they were relevant to science.

  For example, during one of the Science 24 classes, a group of students were having a side conversation while the teacher was leading a class discussion. The teacher tried to get them to quiet down, but then a student explained what they were talking about. The conversation was about a girl they knew who was pregnant and a vegetarian. The students started arguing about whether or not she could be vegetarian while pregnant because of the need for protein. Instead of ignoring the students' conversation and redirecting them, the teacher engaged in the conversation and briefly discussed how vegetarian diets can provide protein and mentioned that they would learn more about this in later units.

  In another Science 24 class, during a discussion on power plants, the following conversation occurred between the teacher and the students:

  S: Do they cause cancer?
  S: Everything causes cancer. Eating 200 Subway subs causes cancer.
  T: Where did you hear that?
  S: Manager at Subway.
  T: Ask your manager, is there a scientific study?

  In this example, the teacher redirected the students comment to emphasize the role of scientific research in validating claims, such as the one mentioned by the student. Overall, by redirecting student comments and discussions to focus on science, as highlighted by these examples, the teacher supported students in relating their everyday experiences to science content and making evaluations of claims that involve science.

- **Respecting student questions, ideas, knowledge, and lives.** In both classes, the teacher created an environment in which students were comfortable sharing their personal experiences and questions.

  As a result, there were many opportunities for students to connect the science they were learning to their own lives. Multiple examples were observed of the teacher valuing what the students had to say and therefore encouraging them to contribute and be engaged in the class. The teacher also demonstrated that she valued students' knowledge by highlighting cases where the students taught her about the topic.

  For example, in the Science 24 lesson on acids and bases, the teacher asked students if they knew how to protect cars from rust. One student made a comment related to powder coating. The teacher asked if the other students knew what that was, which was followed by a number of students providing information about the powder-coating process. The teacher then acknowledged that she had learned something new from the students, because powder coating was not something she was really familiar with. In another class where students were watching the movie *Contagion*, one student had concluded from watching the video that the virus must be airborne. The teacher affirmed what the student had said and then the student responded, "I sounded so smart right there." The teacher then agreed; "You are, you're learning something." Examples such as these highlight how the teacher's responses validated the students' contributions and furthered the creation of a classroom climate that encouraged students to be engaged in the course in ways that provided opportunities for them to connect their learning to their own lives or to examples in the real world, television and media.

Strategy 3: Scaffolded Opportunities for Students to Make Connections to their Own Lives

Another approach the teacher used to help students make connections between the science content in lessons and their own lives was through deliberate scaffolding. More specifically, the teacher built in ways for students to discover how relevant examples could be applied to multiple contexts or to the students' own lives. For example, in one lesson, the teacher used a video from the CurioCity website that showed the relationships between physics and hockey. In previous research, these resources have been shown to be very relevant and interesting to some students (ie, students who play hockey), but not interesting or relevant to other students (Pegg and Brown 2014). However, in this lesson, the resource was implemented in a way that provided a range of students with opportunities to connect the science concepts to their own lives even if they had no interest in hockey. The focus of the lesson was on energy transformations, and the video that was selected from the Let's Talk Science resources explained the energy transformations that were present when a hockey player hits a slapshot. In the initial discussion, a few students who played hockey were very engaged in the discussion of the video and in the creation of a class flowchart showing how energy was transformed during the slapshot. After the discussion of the hockey example, the teacher asked all of the students to create a similar flow chart, but with an activity that they themselves participate in. This application to their own lives provided the opportunity for all students to see the relevance of what they were learning to their own experiences and interests. In a follow-up interview, the teacher mentioned that she had specifically made this modification because of the research project's focus on supporting students to see the relevance of science. In previous years she had had the students create the flow charts with examples she provided.

Evidence of Student Impact

Although this study did not include extensive data from students focused specifically on the impact of the teacher's lessons, data from the classroom observations and student interviews did provide initial insight on the impact that the teacher's practices were having on students and their feelings about them. In addition to the examples described above regarding student input to class discussions, one episode was also observed of students applying what they were learning to their lives outside of the science lesson. During a break, students in the Science 24 class were overheard saying to each other, "Why would you even buy chips after everything you've been learning?" "I'm raising my insulin" (student holding can of cola). Although the students were saying this humorously, it shows that they were connecting their learning to contexts beyond those provided in the lessons.

An interview with one of the Biology 20 IB students also highlighted the value and impact of the teacher's approach. In the interview, the student stated that one of the things that makes the class interesting is "questions from students, the involvement from students. Not just getting taught something, but getting taught something which you want to also be taught about." The student then compared this to classes where the students are disengaged because they don't have the opportunity to ask questions in class:

> They don't have a reason like having the ability to, say, ask questions. They don't have a reason like that to actually pay attention to what the teacher is doing and if they don't have that reason then they might just do nothing and not pay attention at all. … To get people to actually feel the need to do that—they need to ask questions at first.

This statement highlights how the teacher's approach, outlined in the strategies described above, created a classroom climate in which students were encouraged to personally engage with the content and therefore were more invested in their learning.

Conclusions

The quote cited at the start of this paper highlighted the importance of presenting science in a "meaningful context." As teachers, we often focus on how we can identify the meaningful contexts for students; however, what this study suggests is that it is equally important to provide the space within the classroom for students to engage with and identify the meaningful contexts for themselves. For the teacher in this case study, ensuring relevance for students came from a combination of providing possible meaningful contexts (ie, teacher provided examples of science connections to real-world contexts), creating a classroom climate in which students were encouraged to contribute to classroom discussions with their own questions and examples, and reassurance to students that their interests and personal experiences were valued and respected.

Acknowledgements

I would like to thank the teacher described in this study for providing me with access to her classroom and for reviewing drafts of this paper prior to publication. The study was supported by funding from Let's Talk Science.

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Assessing Changes in Scientific Literacy in an Alberta Science Option Course: Myth-Busting Science 25

Kerry Rose

Introduction

Myth-Busting Science 25 is a locally developed Alberta three-credit high school option course. It is interdisciplinary in nature and considers both myth and science as ways of investigating and experiencing the world. It is designed to be highly interactive, with an emphasis on student-led investigations and projects. The course posits scientific inquiry as one way of knowing about the world; science is compared and contrasted with myth as another world view. The students are asked to evaluate the purpose and nature of both myth and science in present and past societies and in their own lives and, eventually, generate their own research questions and investigate them using quantitative and/or qualitative scientific research methods.

Although what we consider to be *scientific literacy* is much debated and, as a term, has changed considerably over the decades, it remains as a stated goal of many science education programs, such as Alberta's: "The secondary science program is guided by the vision that all students have the opportunity to develop scientific literacy" (Alberta Education 2003).[1]

Usually, scientific literacy has the stated aim of having the science student be able to apply classroom learning to the outside world. John Dewey was a pioneer in this type of experiential learning when he suggested that "whatever natural science may be for the specialist, for educational purposes it is knowledge of the conditions of human action" (Dewey 1916, 228). However, theorists and practitioners have struggled with the balance between "a broad intellectual understanding of the natural world and the scientific way of thinking on the one hand, and the utility of science for effective living on the other" (DeBoer 2000, 584). Recent models have also included aspects of metacognition and self-direction within this concept of scientific literacy (Mun et al 2013). Whether the emphasis is on content knowledge or the application of scientific thinking to solve problems outside of the science classroom or lab, there is some consensus that scientific literacy is, at least, "what the public should know about science in order to live more effectively with respect to the natural world" (DeBoer 2000, 594).

Thus, can a course like Myth-Busting Science 25 increase the scientific literacy of high school students? One of the authors of this course, during the first semester that it was offered, used a mixed-methods approach to inquire into changes in student conceptions of science (and myth) in three sections of this newly offered option course. The results suggest that using a course like this as an intervention can and does change students' perceptions and ability to apply scientific ideas to the outside world, but in ways that the course developers did not fully anticipate.

Learning Theories

Transformative learning theory, first identified by John Dewey in the early 20th century, describes how the "interaction between man and his environment, mediated by tools and language, constitutes the foundation of knowledge" (Miettinen 2006, 391). In this tradition, "subjects and objects co-emerge and become interactively transformed in the reality-transforming practical activity" (Miettenen 2006, npn). In other

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[1] Immediately following this statement is the corollary: "Students will develop the science-related knowledge, skills and attitudes that they need to solve problems and make decisions, and at the same time help them become lifelong learners—maintaining their sense of wonder about the world around them" (Alberta Education 2003).

words, in the process of working with and through activities and practices, it may be possible for learners to transform themselves and their environment in ways that may open both the individual and the system surrounding them to new perspectives and possibilities.

As a philosophy of learning, transformative learning theory ontologically supports an interventionist approach to learning in science and the investigation of such. These ideas, further elucidated in the early 2000s by Mezirow (2000) and Taylor (2008), among others, enable action that is more creative and constructive than more instrumental approaches to learning. Those that feel somewhat powerless in our present educational systems are encouraged to use activities and practices that are open ended and exploratory to support learning "through the soul" (Mezirow 2000, 6). Central to this idea is the interrogation of the structures—the history and cultural traditions—that underpin our present understandings of the world. The strategies that may lead to this type of transformative learning include large- and small-group discussion, journalling and other student-led investigations.

Although Mezirow envisioned transformative learning to be mostly an adult experience, it was with this construct in mind that this new Alberta science option course—Myth-Busting Science 25—was conceived. It was developed by two veteran Alberta science teachers who were themselves becoming aware of how limited their own conceptions of science as a world view were and, at the same time, becoming frustrated with an apparent lack of awareness of both the power and peril of scientific thinking on the part of their high school science students. Was it possible to use the tools of transformative learning theory to promote more meaningful and engaging science education and, at the same time, allow students to explore their own world views as their teachers had recently done? Transformative learning theory was used in this case as a construct to guide curriculum design and as a theoretical lens supporting the methodology used to investigate this intervention.

Goals of the Course

This course had two overarching goals as envisioned by the developers. The first was to have students better locate scientific thought within the broad spectrum of human knowledge and experience, and to be able to critically evaluate some of the many myths that persist today, while at the same time appreciating nonscientific approaches for their contributions to our cultures and world views. The second was to enable students to better find, evaluate and synthesize information—especially in the world outside of the science classroom—using scientific approaches when appropriate. Both of these goals fall under the *scientific literacy* umbrella. The course's emphasis on student-directed learning topics and problems is also congruent with the more recent additions of self-direction and metacognition to the definition of scientific literacy. The title of the course reflected a popular television series at the time, called *MythBusters*,[2] that featured novel approaches to debunking popular cultural myths. The title was designed to stimulate student interest in the course, since it was optional, and yet be descriptive of the content that students would be encountering.

The course began with an analysis of myth and student projects about many types of myths, from religious and culturally significant ones (eg, creation, religious, apocalyptic) to those derived from popular culture (eg, chewing gum stays in the stomach for seven years, alligators/snakes in sewers). The course then took a condensed trip through the history of science (again using student-generated materials), and eventually discussed the nature of science (NOS) and how it differs from other world views. The role of media in disseminating scientific theories and discoveries, and the ethical and unethical practices of science were also interrogated. Students eventually proposed their own myth to bust and, as a capping project, performed an investigation, critiqued and evaluated it, and presented their findings to the class.

General Learner Outcomes

This course had the ambitious aim of surveying the evolution and the present role of both science and myth in society. Another stated goal was to encourage students to become critical evaluators of information from various sources and also become designers of investigations into claims to knowledge. Alberta Education requires that locally developed courses clearly state these general learner outcomes (GLO) in the curriculum proposal before approval. These GLOs were intended by the authors to be addressed in approximately the order they are listed as the course progresses, although all of the GLOs reinforce each other:

- Students will develop an understanding of the role of myth in early and modern societies.
- Students will understand how scientific inquiry differs from myth and other ways of thinking.
- Students will develop a general understanding of the historical evolution of the process of scientific inquiry.
- Students will be able to identify, apply and evaluate modern scientific methodologies that answer questions about the world around them.
- Students will be able to critically read and evaluate information and popular claims.
- Students will be able to design and perform inquiry projects that dispel common modern myths.

Project-Based Pedagogy

This course was designed for a project-based learning pedagogical approach. Projects, according to Thomas (2000), are "complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations" (p 1). In order to be truly project based, the course should have projects that are "central, not peripheral to the curriculum, … [be] focused on questions or problems that 'drive' students to encounter (and struggle with) the central concepts and principles of a discipline … [be] student-driven to some significant degree … [and be] realistic, not school-like" (Thomas 2000, 3–4). This type of pedagogical approach is also congruent with the goals of this course; student decision making aims to increase their engagement with the subject matter.

Each major topic in this course required students to create and share their findings from their investigations into a topic. This included video documentaries about various myths, research posters about historical scientists and their eras (displayed and discussed as a timeline), short inquiry-type projects on topics such as "water-witching" or paper airplanes, evaluations of media reports on science stories, and eventually a capping project that asked each student to "bust a myth"of their choice. This final project asked students to submit a proposal with a description of the previous research on the topic, the methods needed to carry out the investigation, the ethical and safety considerations involved and the value of this research. This proposal had to be approved by both the classroom teacher and an administrator at the school, giving students some insight into the process that scientists encounter in an academic setting. Students would then carry out their research, design a research poster and present it to the class; the presentation would include the limitations and errors in their investigative process and design.

This process allowed students to see many creative and imaginative ideas from their peers and how each could be interpreted scientifically. Although modelled on the popular television show, the approach asked students to pay more attention to the scientific limitations of their investigations. Topics such as "Can People Tell when Someone Is Staring at Them?" (from behind), or "Does Playing Video Games Increase Hand–Eye Coordination?" allowed students to apply scientific principles to topics that were of interest to them, while helping them appreciate some of the difficulties often encountered by scientists in their work, including the limitations of small sample sizes, participants that were not perfectly cooperative and administrative hurdles (for example).

Research Methods

Evaluation of this course occurred as part of the master's degree project of one of the authors (and a teacher) of this course. Prior to proceeding, the authors obtained ethics approval from Athabasca University and the school district in which this research took place. Participants in this study were high school students, 15 to 18 years of age, enrolled in Myth-Busting Science 25 at a large Alberta high school. The course was presented as an option during the school's registration process; demand was very high when it was originally offered—over 100 students were originally enrolled in three sections during the first semester it was offered. The course has approximately 63 hours of instruction; during one of the first classes, a precourse survey was administered to all students who wished to participate. On one of the last days of the course, a postcourse survey that was almost identical to the precourse survey was administered, and the differences between the responses were compiled and analyzed. The survey consisted of both a numerical response (Likert-type) question section and a more open-ended

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[2] http://www.discovery.com/tv-shows/mythbusters/

section. Questions enquired into students' conceptions of what myths were and their value, and the relevance of NOS to the students' everyday lives. NOS questions were modelled after a questionnaire developed by Lederman et al in 2002. Questions about myth as a world view were composed, using the stated goals and learning outcomes of the course.

Students (N=46) completed both the pre- and postcourse surveys, and these were used to compare the changes in student responses over the time period of the study (a single semester—five months). Once the results had been evaluated, a focus group was conducted with several students, selected on the basis of their diverse genders, academic performance and attitudinal perspectives, with questions that addressed the trends that arose from comparing the pre- and postcourse surveys. This triangulation resulted in several significant themes emerging from the data. It was clear that this course did change some of the perspectives of the students, but not always in ways that the course authors intended. Other aspects of the students' conceptions of science did not change in significant ways.

Since one of the course authors was also the teacher of the course and the person doing the evaluation of the surveys and focus group results, it was imperative that several ethical considerations were made. First, the surveys were conducted by an invigilator who was not a teacher in the school. The invigilator created a list of student names that corresponded to numbers; survey responses were tracked via these numbers. He then stored the surveys separately from the list of names/numbers. The teachers of the course and the survey evaluator had no access to the surveys until the study was complete, and the student surveys remained anonymous to the course evaluator. The focus group facilitator and transcriptionist was also not a teacher and not known to the students. The focus group transcripts also remained anonymous to the course evaluator. Finally, the data supporting the themes that arose was reviewed by the evaluator's academic supervisor to ensure reliability. It was found that all three sources of data—the numerical response questions, the written response questions and the focus group responses—did triangulate and it did become apparent that there were repeating and dominant themes in the data.

Results Summary

Four themes emerged as the data was analyzed:

1. The students, upon exposure to a more tentative and nonpositivistic view of science, were more aware of the changing and noncertain nature of science as a human endeavour.
2. Awareness of the importance of ethical and moral considerations that can and do affect scientific research increased.
3. The understanding that myths are a way of knowing about the world that contributes to people's world views and have value as such increased.
4. Students were eager to engage in activities that were hands on and expected a course like this to involve active learning and participation as a process of learning.

Nature of Science Results

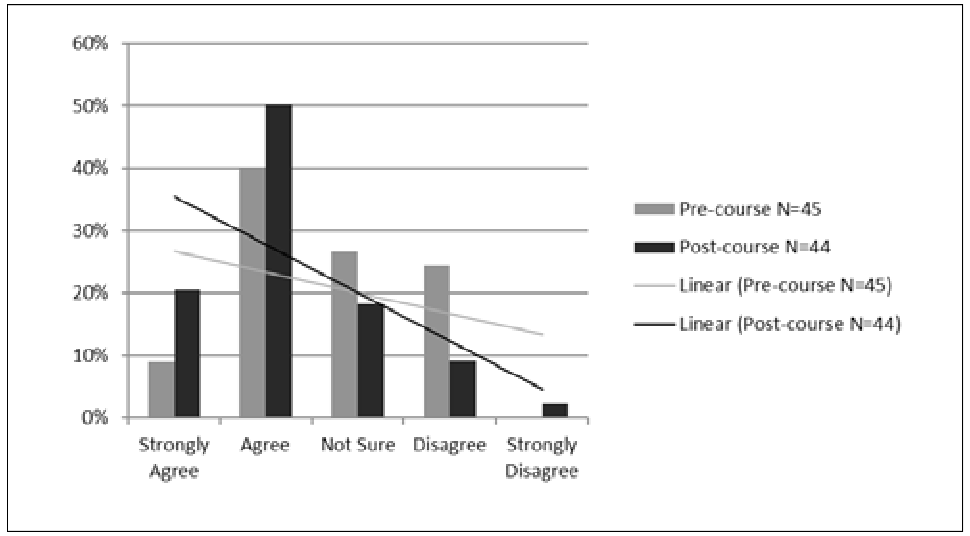
Some of the most substantial changes in the students' view of science occurred as part of the first theme above. Students became more willing and able to question scientific (and other) claims about the world, so much so that they often expressed that they had become less willing to believe *any* claim about the world. Students showed some degree of inability to gauge the reliability of scientific research; their confidence in their ability to evaluate scientific and other claims did not substantially increase by the end of the course. This points to a weakness in the course implementation—if skepticism is a skill that can be taught, so too can skills that allow one to be more or less confident of a claim. This is an area that could be improved in future delivery of this course curriculum.

Students also became more aware of the effects of outside factors on science, including ethical and political/financial issues. Other interesting, although not statistically significant, results indicated that fewer students thought scientists were open minded, more students thought that religious/spiritual thought was compatible with scientific perspectives and more students agreed that science rests on the assumption that the natural world cannot be altered by a supernatural being. Student ratings of scientist honesty were lower, and fewer students thought that science produces the only true form of knowledge. Many other questions inquiring into NOS themes and the application of science to everyday life showed very little change between the pre- and postcourse tests.

Samples of the Results

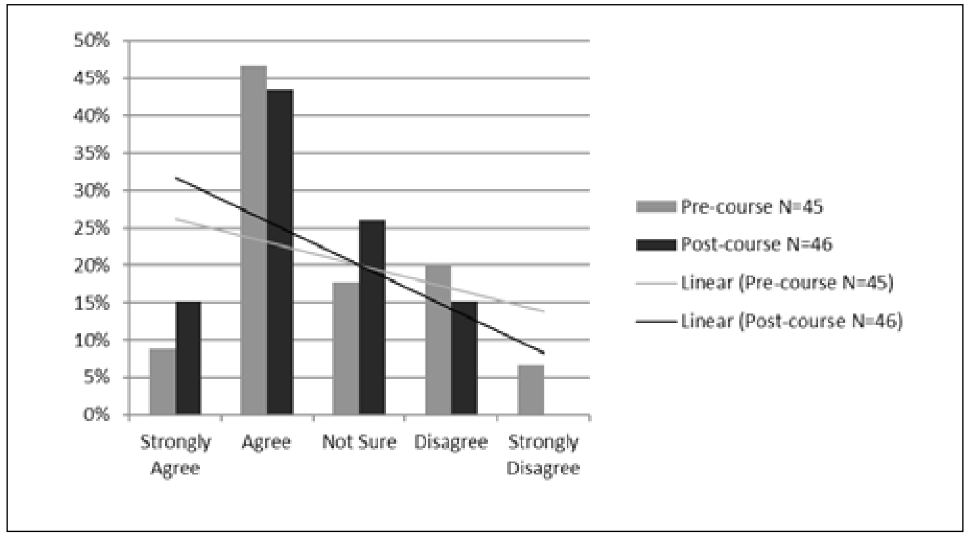
Sample Survey Questions

As scientists learn more, most scientific ideas we use today are likely to be proven wrong.



T-test Confidence Level = 0.94[3]

To understand science, I sometimes think about my personal experiences and relate them to the topic being analyzed.



Test Confidence Level = 0.89

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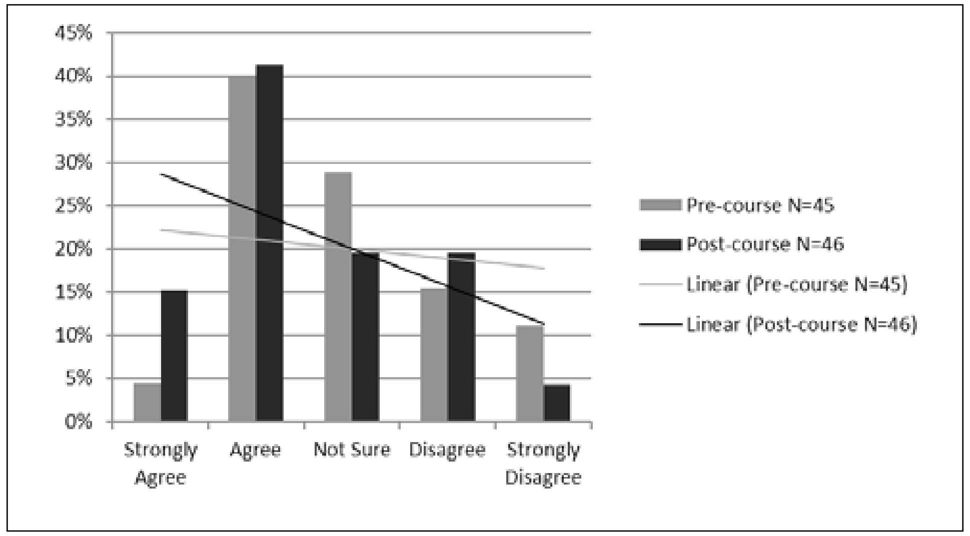
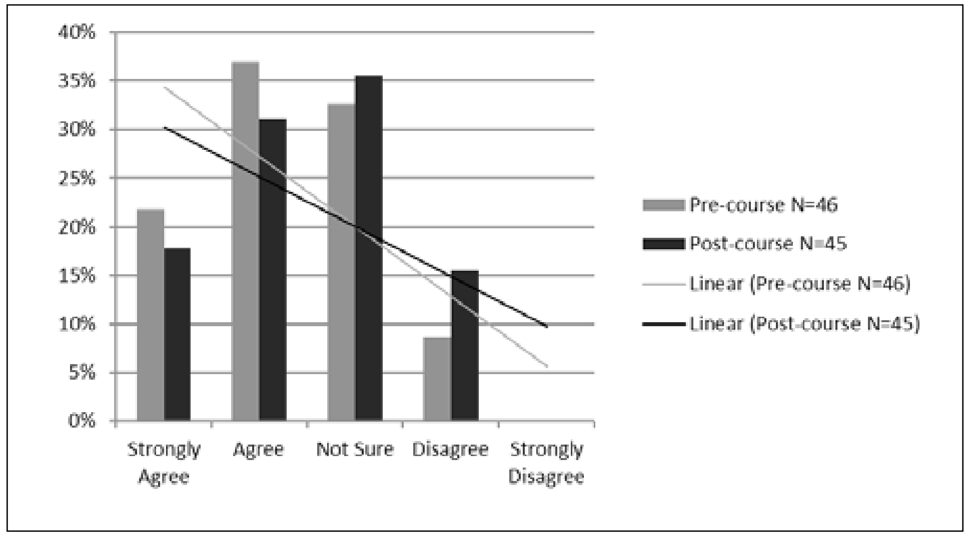
[3] This means that we are 94 per cent sure that there is a difference in the population means based on our sample means. Most statisticians consider confidence levels of 90 to 95 per cent statistically significant.

Science can help people make some moral decisions (that is, one group of people deciding how to act towards another group of people).



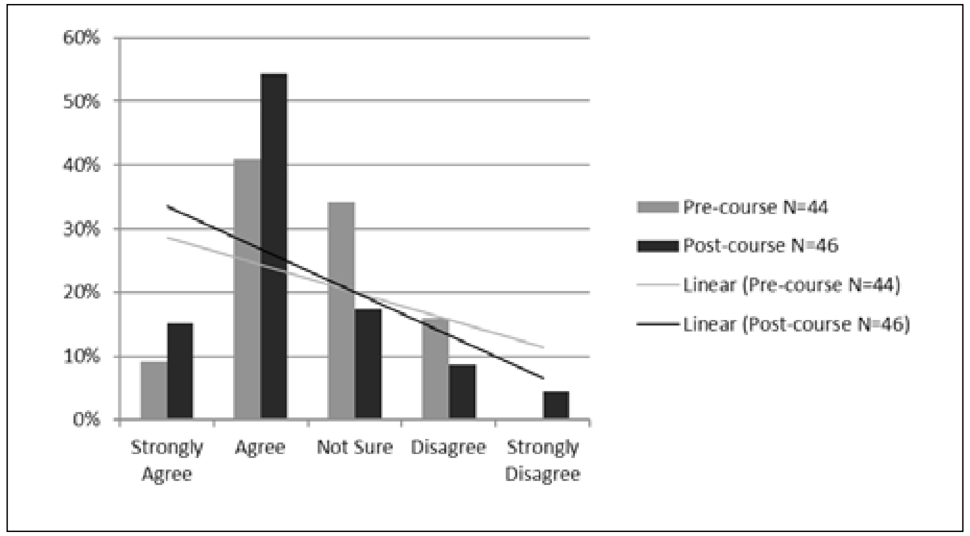
T-test Confidence Level = 0.91

Scientists are open-minded.



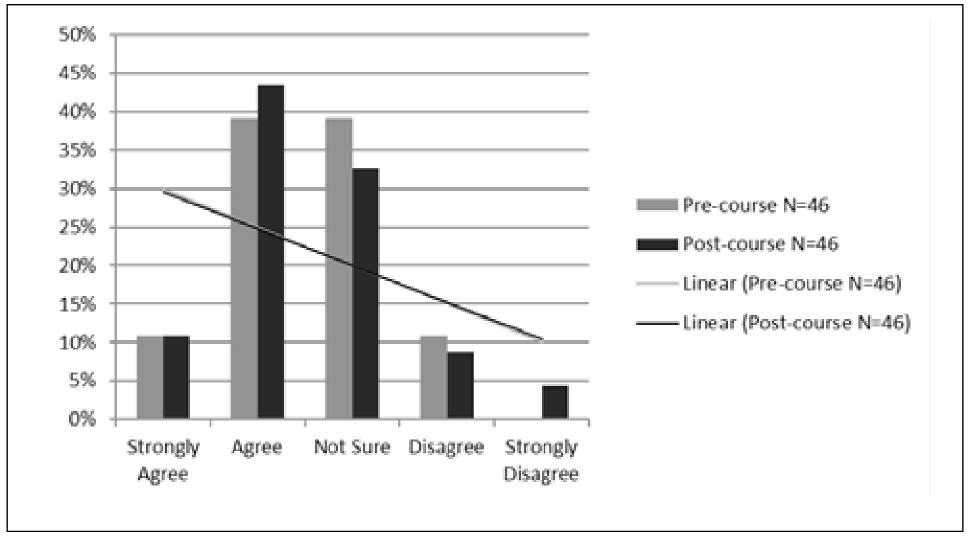
T-test Confidence Level = 0.86

Science is relevant to my everyday life.



T-test Confidence Level = 0.88

Scientists are influenced by historical events.



T-test = Not a statistically significant difference

Myths as World View Results

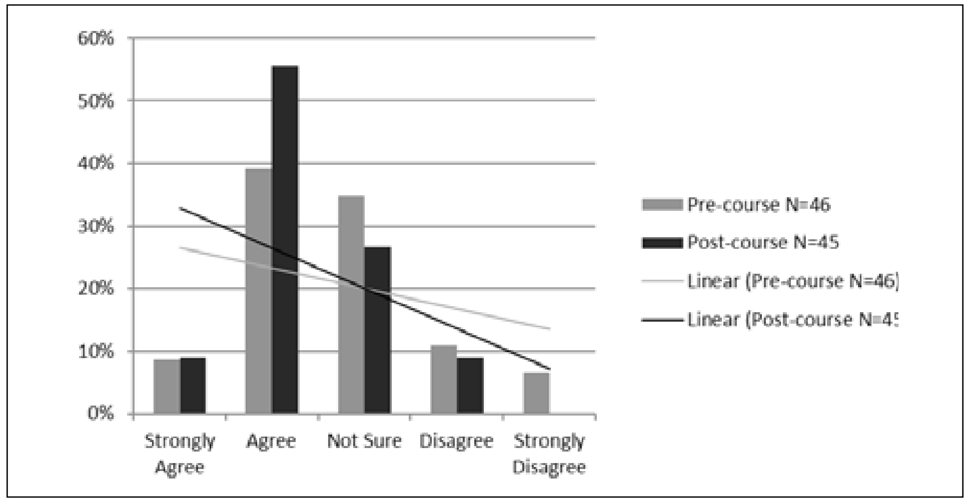
In this course, myths were defined broadly and included popular myths (eg, urban legends), cultural myths (Aboriginal stories) and classical mythology (eg, Greek or Roman gods). Students were asked to explore the broader uses and meanings of myths in many societal situations.

The results of the study showed that fewer students agreed that myths were stories that are not true, and more agreed that myths convey information to people that might be valuable. More students agreed that myths are used to explain things that science cannot. Both pre- and postcourse, many students thought that myth and science were both valid ways of knowing about the world.

Students also expressed, especially in the written response section and the focus group, more appreciation for the value of myth (whether or not they believed in them) and became more inclusive in what they defined as a myth. The students were very interested in the myths of other cultures and especially of the teen subculture, and were able to better see how myths tend to repeat themes of moral or culturally acceptable behaviour.

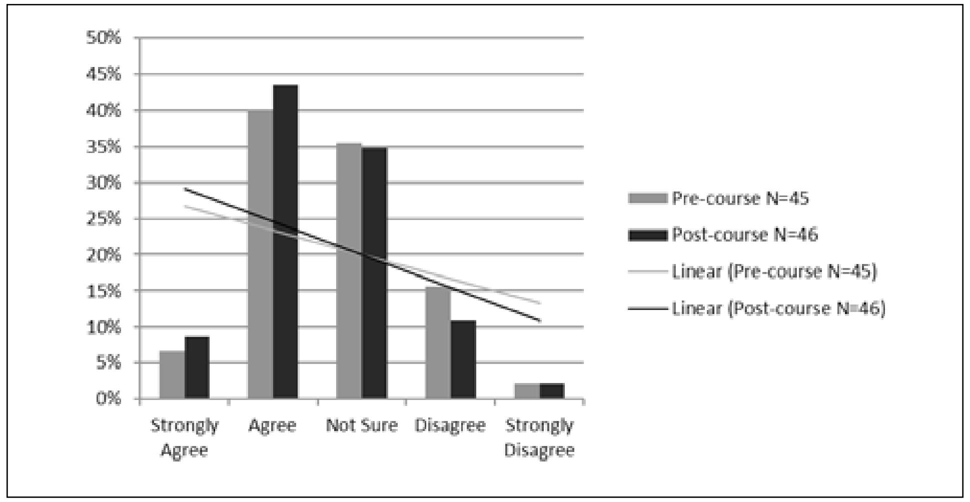
Sample Survey Questions

Myths convey information that may be valuable to people.



T-test Confidence Level = 0.92

Myth and science are both valid ways of knowing about the world.



T-test = not a statistically significant difference

Other Feedback from Students

More students reported that science had a relation to what they experience in the real world, and that science was relevant to their everyday lives. More students reported that they thought about science that they experience in everyday life. However, these results were not statistically significant. A higher proportion of the students surveyed reported that they agreed that science has caused environmental problems, and a higher proportion of the students agreed postcourse that scientists are concerned with the potential effects that result from their discoveries, but again, the results were not statistically significant.

Students, both in the open-ended questions and in the focus group environment, reported that they valued and expected this science option course to involve much active learning. They had some expectations from the television show (*MythBusters*), which had individuals that do active experimentation. Some students expressed that although they liked this type of learning, they thought that this iteration of the course was disappointing in that not all of the activities involved this type of learning.

The teachers of this course found it difficult with large classes of students with varying ages and abilities to continually encourage this to occur. Group dynamics and some school policies made it difficult to achieve the goal of a totally student-directed learning environment in the high school setting. This was consistent with other studies involving project-based learning. In these studies, as in this situation, teachers often "experienced difficulty in balancing student engagement in dialogic versus monologic or authoritative discussion interactions" and "they encountered … lack of student initiative and engagement" (Hasni et al 2016, 210–13). Students often had difficulty with the complex and metacognitive tasks that they were asked to perform, including designing their own investigations. Subsequent iterations of this course took this into account; more time was spent on working with students to narrow research questions, to find ways to test them with limited time, equipment and/or participants, and to practice evaluating research.[4]

Conclusions

Although the study was somewhat limited by the sample size of students that participated in both the pre- (N=46) and postcourse surveys (one student did not answer all the questions, thus N=45), the data shows that some student perceptions of science and its use did change over the time frame of this short course. The participants were mostly male and mostly white, but inclusion of females and ethnically and academically diverse participants in the focus group may have helped to balance the results.

This study indicates that it may be possible to significantly shift student perceptions of the NOS and the value of alternative worldviews. This is encouraging—inclusion of more explicit NOS activities and attention to the use of scientific principles for topics outside of the traditional science curriculum may increase the scientific literacy of students in a relatively short span of instructional time, using student-directed projects and topics to increase engagement. However, this does point to the perils of encouraging scientifically skeptical learners. When students become more aware of the tentative and uncertain NOS, this should be balanced with learning how to evaluate claims and, therefore, to put more trust in those that are more robust and trustworthy if a more balanced scientific literacy is to be achieved. Students in this course indicated that they had learned skepticism but reported little confidence in evaluating claim validity.

Myth-Busting Science is presently being offered at the original school where it was developed and now at other schools and school districts in Alberta. It has proven to be a popular student choice. Teachers interested in offering this course for credit at their school should contact the author of this paper for more information.

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[4] Critiquing episodes of *Mythbusters*, scientific reports or media clips was a popular and effective way to do this.

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Integrating Citizen Science into the Classroom to Support Inquiry-Based Learning

Wendy Simms

Public participation in scientific research is often referred to as *citizen science* (Dickinson and Bonney 2012). It represents a partnership between professional scientists and volunteers to gather or process data in an effort to better understand and address a scientific problem. While citizen science is not a new concept, major advances in information and communications technology (ICT), as well as increased access to mobile technologies, have made it much easier to contribute to scientific research on both a local and global scale (Silvertown 2009). But what does citizen science actually look like? In many cases, citizen science is simply the act of following simplified scientific protocols to collect or analyze data. While this may sound intimidating to the nonscientist, there are many types of projects that can accommodate participants of diverse backgrounds with varying levels of education, experience and time.

Citizen Scientists as Collectors of Data

Including nonscientists in the data collection process allows research to occur over a larger geographic scale, more frequently and for longer periods of time than would otherwise be possible by a typical research team. There are thousands of contributory citizen science projects worldwide that have participants collect and contribute data using systematic protocols designed by scientists (Bonney, Ballard et al 2009). For example, Project Noah has participants use their GPS-enabled mobile devices to photodocument plants and animals in their local environment, contributing to a global inventory of biodiversity. The Indicator Bats Program (iBats) has an app that allows participants to use their mobile devices to record and upload bat calls to help scientists monitor abundance and distribution. Millions of participants around the world submit checklists of their bird observations to eBird to support research on bird conservation. The Lost Ladybug Project monitors native and introduced ladybug populations by having participants submit photos of ladybugs, along with the time, date, location and habitat. The Great Sunflower Project has participants report bee activity in their garden to monitor pollinators. This contributory model of citizen science is particularly valuable for environmental monitoring and biodiversity studies, which make up a large proportion of the citizen science projects worldwide.

Citizen Scientists as Analyzers of Data

Advances in digital and mobile technologies have resulted in the generation of enormous amounts of scientific data that needs to be processed and analyzed. Many projects have recognized that humans are superior to computers when it comes to image and pattern recognition, and have included nonscientists in the analysis of digital data. For example, participants of Galaxy Zoo have classified millions of images taken from the Sloan Digital Sky Survey. The completely online project has been hugely successful—within 24 hours of its launch, the Galaxy Zoo website was receiving 70,000 classifications per hour by nonscientists (Galaxy Zoo nd). Neptune Canada has collected thousands of hours of underwater video footage that is currently being analyzed by citizen scientists. Participants of Digital Fishers watch 15-second underwater video clips and record their observations to help scientists explore deep-sea communities. Penguin Watch has participants examine online photos and mark observations of adult penguins, chicks or eggs to help scientists monitor penguin populations. CellSlider and its newest version, TrailBlazer, have participants identify cancer cells in breast tumours to help doctors determine appropriate treatment. Projects that have been designed using a game-like platform have also been extremely successful in the analysis of scientific data (Cooper et al 2010). FoldIt is a game that has players compete to solve an online 3-D puzzle to help scientists understand how proteins involved in HIV, cancer and Alzheimer's disease can be treated (Hand 2010). Virtual citizen science projects such as these are greatly increasing in application due to advances and accessibility of technology and software (Wiggins and Crowston 2011).

Citizen Scientists as Active Participants in Their Local Place

Citizen science can also be a means for participants to connect with their local place and act as environmental stewards as they collect or analyze data that help scientists understand and address socioecological issues such as climate change, invasive species, habitat loss or pollution. The World Water Monitoring Challenge is an international program in which volunteers sample their local waterways and share results online to educate the public about their impact on water quality. Project Budburst has participants submit observations of local plants as they leaf, flower and fruit throughout the year, in an effort to understand the impacts of climate change. Project Globe has participants use standardized protocols to observe changes in clouds, water, plants and other life in support of climate research. Global human monitoring networks such as these have contributed greatly to our understanding and action towards environmental issues of the 21st century (Conrad and Hilchey 2011; Cooper et al 2007; Sullivan et al 2014).

It has been suggested that "next-generation citizen science" will actively incorporate social networking systems to influence stewardship behaviour and global cooperation towards sustainability (Dickinson and Crain 2014). YardMap is a citizen science project that collects microhabitat data in a Google Maps interface. The habitat is characterized according to practices (pesticide use, water usage, planting native species), and data is integrated with bird monitoring data to examine the impact of small-scale landscape manipulations on distribution. However, YardMap is unique in that it also functions as an interactive social network, designed to support, display and reward activities of individuals within a large conservation community. The influence these communities have on stewardship behaviour and collective action will need to be explored.

As described above, there are many typologies of citizen science (Bonney, Ballard et al 2009; Wiggins and Crowston 2011). However, the remainder of this paper will focus on environmental citizen science and its potential to support inquiry-based learning in the classroom.

The Educational Value of Citizen Science

While the scientific benefits of citizen science are becoming more recognized, evidence of its educational value is also mounting. Citizen science has been shown to enhance engagement and interest in science, increase scientific literacy, develop science-related skills and contribute to lifelong science education (Bonney, Cooper et al 2009; Haywood 2014; Wals et al 2014). As funding agencies call for a broader reach, citizen science project designers are providing a multitude of resources to increase engagement and enhance the educational value for participants. Online tools to visualize data, training modules and quizzes, access to raw datasets, newsletters to share results and stories, reward systems, direct interaction with scientists, and discussion forums are just some of the examples. Many citizen science projects are also actively collaborating with science educators to support teachers directly by providing lesson plans, teacher guides and professional development opportunities (Trautmann et al 2013; Trautmann et al 2012). Citizen science, which has often been associated with informal learning environments, now has great potential to support student inquiry in the formal K–12 classroom.

In response to this innovative approach to science education, I have been studying the impact and design of a citizen science project that has been formally integrated into classrooms of the Nanaimo Ladysmith Public Schools District 68 (SD68), in British Columbia. This initiative coincides with the release of new provincial curriculum guidelines that call for a more open-ended and competencies-based approach to education (British Columbia Ministry of Education 2015). Collaboration was formed between Grade 5 teachers from SD68, science educators from the Nanaimo Science and Sustainability Society (NS3) and local ecologists from Vancouver Island University (VIU) to develop the NS3 Intertidal Monitoring Project.

An Example of Citizen Science in the Classroom: The NS3 Intertidal Monitoring Project

The NS3 Intertidal Monitoring Project was specifically designed so that Grade 5 students in Nanaimo could participate in a local research project monitoring an invasive species of clam that was introduced to British Columbia in the early 1990s (Dudas, Dower and Anholt 2007). A pilot of the citizen science protocols was run in 2014, which had students follow a scientific protocol to collect, identify and measure clams before visiting an education station to learn about intertidal ecology. Participation took approximately one hour.

Although the citizen science experience was deemed extremely successful from a student engagement perspective, personal observation suggested that students needed an opportunity to apply what they had learned from the experience. While they were receiving guidance on how to "act like a scientist," I felt they needed to practice *thinking* like a scientist for a deeper learning experience. Bonney, Ballard et al (2009) note that many emerging citizen science projects fail to cultivate the educational component of the citizen science experience. Furthermore, research shows that simply participating in data collection does not increase the understanding of the nature and process of science (Jordan et al 2012). DeWitt and Storksdieck's (2008) review of educational field trips recognizes that follow-up work in the classroom can maximize the learning potential of field trips. Specific design of classroom curriculum to supplement the citizen science experience could allow time for reflection and give students the opportunity for active experimentation and deeper learning (Kolb 1984; Thomashow 1995). As a result, funding was secured from VIU, and the development of supplementary educational classroom curriculum for the NS3 Intertidal Monitoring Project began. An interdisciplinary team was created that consisted of VIU scientists, NS3 science educators and me, the principal designer.

After consulting with practitioners to determine their needs and constraints, we developed a classroom activity that expanded upon the concept of scientific protocols, using the provincial curriculum (British Columbia Ministry of Education 2015). Students were given an adapted newspaper article about a current issue such as toxic algae blooms killing whales in the Pacific Northwest, the impact of global warming on polar bear habitat, or increased cougar sightings in Nanaimo. Students were reminded of the sampling protocol they had used to monitor varnish clams, and then were asked to apply those concepts to design a sampling protocol that could monitor the issue described in their article. Students then created a short video to pitch their research idea to peers and a panel of judges that represented a granting agency capable of funding their research.

A case study of the NS3 Intertidal Monitoring Project and the supplementary classroom activity that was implemented in two classrooms was completed in June 2016. To ensure that different aspects of the student learning process and experience were captured, multiple types of data were collected. Participant observations were recorded as field notes throughout all components of the program. Student learning artifacts (worksheets and videos) were collected and the student conversations during the creation of the video pitch were audiorecorded. Due to class time constraints, it was decided that student interviews would be difficult to request; instead, a student exit ticket that asked four questions was handed out at the completion of the activity. At the end of the project, Grade 5 teachers were asked to participate in a semistructured, in-depth interview to voice their practitioner perspective on the design of the project and how it affected student learning.

In this case study, evidence of student engagement in the process of scientific investigation and communication was immediately evident. Supplementing the contextual learning experience of participation in real scientific research with classroom activities that allowed more student control gave students a deeper understanding of the nature of science. The remainder of this paper will use excerpts from this research, as well as other peer-reviewed research, to espouse the educational value of citizen science and discuss its potential to support teachers and students in the transition of classrooms into more inquiry-based learning environments.

Inquiry-Based Learning and Citizen Science

In the past 30 years, there has been a call within science education to shift the emphasis away from teaching foundational content knowledge as a distinct entity and blend it with the knowledge and skills obtained by student participation in authentic scientific practices (National Research Council 2012; Songer and Kali 2014). Engaging students directly in scientific investigation through the use of inquiry-based activities has long been argued as an educational strategy to promote this fusion and generate a deeper conceptual understanding, as well as disciplinary "ways of knowing" (Sawyer 2014; Songer and Kali 2014).

Inquiry is an approach to learning that moves beyond confirmation activities, in which students follow a linear set of instructions to verify an answer or confirm a principle. An inquiry approach uses investigations to provide the impetus for communities of learners to increase their understanding of an authentic problem, topic or issue that does not have a definitive answer (Kuklthau, Maniotes and Caspari 2007). It can range from structured inquiry (students use established procedures to investigate a question that has been provided) to guided inquiry (students design their own procedures to address a question that has been provided) and open inquiry (students generate their own research questions, design an experiment, analyze their results and communicate their findings) (Trautmann et al 2012). While participation in citizen science can fall anywhere on this spectrum, it often begins as a structured form of inquiry with scientists supplying the question and protocols for investigation. This was true of the NS3 Intertidal Monitoring citizen science project, which had students monitor and invasive species of clam using protocols designed by scientists.

Open inquiry is an approach to science education that harnesses the natural curiosity of students to generate their own research questions and conduct their own investigations. The complex scientific process is then divided into "smaller, logically connected units that guide students and draw attention to important features of scientific thinking" (Pedaste et al 2015, 48). These units, or inquiry phases, form what has often been referred to as the *inquiry cycle*, although inquiry is rarely a linear process. A well-known example is the 5E instructional model of inquiry-based learning, which leads students through a progression of inquiry phases termed *engagement*, *exploration*, *explanation*, *elaboration* and *evaluation* (Bybee 2009). Open inquiry activities are not taught, but rather facilitated by educators, who engage students to generate their own questions and then support a deep exploration of that topic through investigation and discovery (Kuklthau et al 2007). This requires a much different role for teachers, who now need to strategically scaffold and guide individual students through the inquiry process to enable them to perform complex tasks outside of their abilities (Reiser and Tabak 2014).

While many educational inquiry models exist, a comprehensive review of the literature revealed that the terminology used by different researchers varies, but the inquiry phases described by different researchers show much overlap conceptually (Pedaste et al 2015). As part of their review, Pedaste et al proposed a new inquiry-based learning framework, one that is dynamic and representative of inquiry in practice (Figure 1.0).

The renewed emphasis on inquiry-based learning in education comes from research in the learning sciences, which has repeatedly shown that a deeper, more conceptual understanding of science occurs when students engage in authentic practices to actively construct their own knowledge (Sawyer 2014). While these sophisticated practices are typically outside of students' existing capabilities, scaffolding can be used to simplify elements of these authentic practices to make it achievable (Reiser and Tabak 2014). Scaffolding comes in many forms, but can include the modelling of actions by a "more knowledgeable other," strategic prompts that focus attention or cause reflection, software materials that offload complex tasks that are unproductive for learning, or platforms for discussion, to name a few (Reiser and Tabak 2014).

As authentic, inquiry-based learning opportunities continue to be identified as a priority in education, citizen science should be explored as a way to scaffold teachers and students in the transition of classrooms into more inquiry-based learning environments. A 2015 Horizon report highlights community partnerships with citizen science as a valued approach to science education for this reason (Johnson et al 2015).

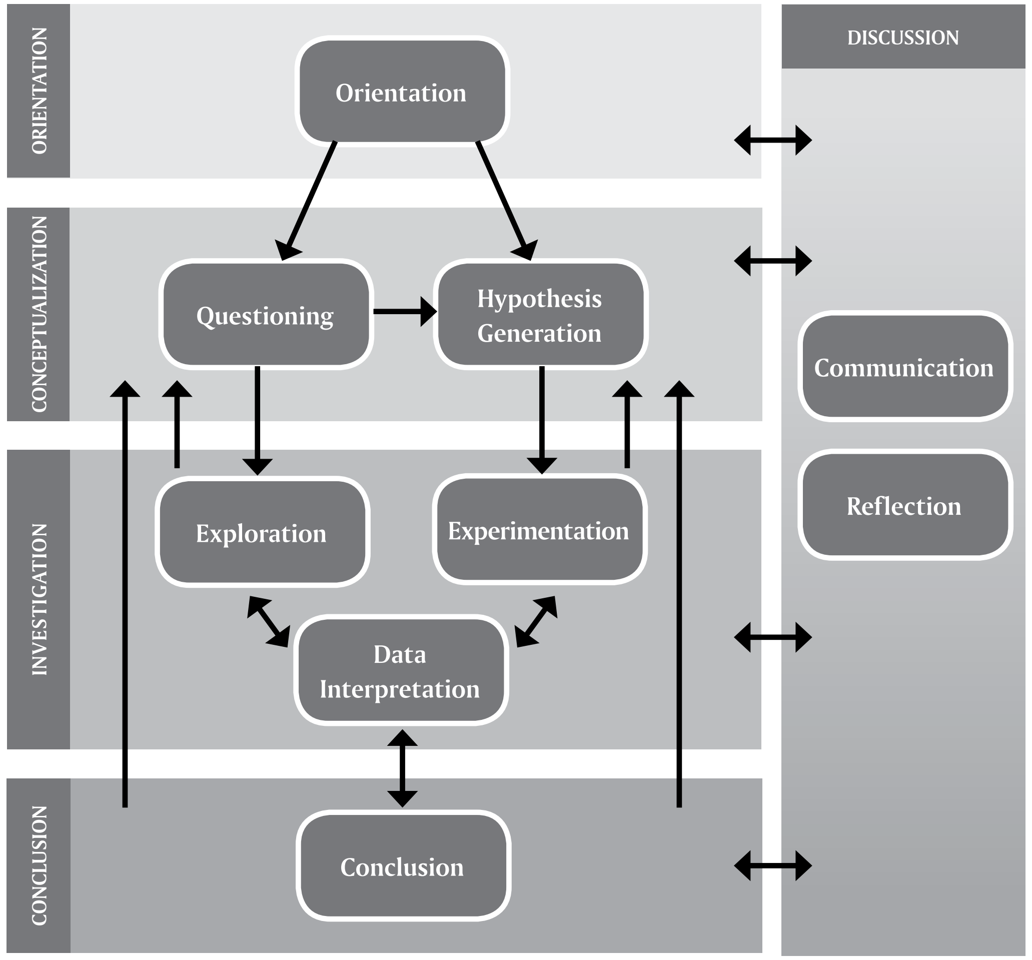

Figure 1.0. Inquiry-Based Learning Framework Proposed by Pedaste et al (2015)
From "Phases of Inquiry-Based Learning: Definitions and the Inquiry Cycle," by M Pedaste, M Maeots, L A Siiman, T de Jong, S A N van Riesen, E T Kamp, C C Manoli, Z C Zacharia and E Tsourlidaki. 2015. *Education Research Review* 14, p 56. This image is licensed under a Creative Commons licence Attribution–Noncommercial-NoDerivatives 4.0 international licence. *Editor's note: This image was modified to improve readability. No content was changed.*

Act Like a Scientist, Think Like a Scientist, Become an Informed and Active Citizen

An inquiry-based learning approach allows students to construct their own knowledge through personal discovery, which supports the development of 21st-century skills such as systems thinking, communication and problem solving (Bybee 2009). While the majority of students may not go on to become professional scientists, Sadler, Barab and Scott (2007) eloquently note that "life in the 21st century is irrefutably associated with science and technology, and formal education should help students prepare for active participation in modern democracies" (p 373). The development of 21st-century skills will enable students to become informed and active citizens that might collectively be able to address the local and global issues we face today. This concept of science education for citizenship is not new (Roth and Lee 2004).

As a researcher involved in the design of the NS3 Intertidal Monitoring citizen science project, it was rewarding to watch Grade 5 students diligently follow a scientific protocol to collect data on an invasive species of clam. Students carefully collected, identified and recorded their data. They added their data to the project graph and began to consider why their data point was different from another group's data point. The learning experience had physical context (they were situated in the environment where the problem was being studied), personal context (the experience occurred in their local place) and social context (they were engaged in working directly with scientists and peers) (Falk and Dierking 2000). Content knowledge was blended with process knowledge, and learning about science became meaningful as a result of the authentic research experience. Students were engaged because their participation in the scientific process was real, and they recognized that their contribution mattered. When students were asked to describe in their own words what it meant to be a citizen scientist, they used words such as "fun," "cool" and "amazing." But more important, reflective comments such as "It means helping your society," "Not to ignore problems" and "It's an honour to be helping problems in the world" all support the idea that citizen science can take learning well beyond classroom walls by empowering students as they contribute to building knowledge in their local and global communities.

Using Citizen Science to Develop Inquiry Readiness

While the call for more inquiry-based learning opportunities in education has been made clear, teachers are often left wondering how to implement this teaching strategy in practice. Transitioning traditional science curriculum into a more inquiry-based approach to learning can be daunting for both teachers and students. Research supports the idea of *inquiry readiness*, and suggests that scaffolds need to be in place to progressively guide students toward true open inquiry, where students pose their own research questions and design the investigation (Songer 2006). Students can have difficulty with all phases of the inquiry process, particularly developing their own ideas and curiosity, designing valid experiments, and interpreting and discussing results (Yoon, Joung and Kim 2012). While some students may thrive on the opportunity to take charge of their own learning, other students will not be confident in their abilities or knowledge, and others may become distracted by the change in classroom structure. These challenges further support the need for scaffolds that model processes, focus attention, cause reflection or offload complex tasks that are unproductive for learning (Reiser and Tabak 2014).

Teachers' knowledge, confidence and understanding of the inquiry process have been shown to play a crucial role in implementing inquiry-based activities (Bahbah et al 2013; Wallace and Kang 2004; Yoon, Joung and Kim 2012). As a result, the concept of inquiry readiness may apply to teachers as well. Teachers need time to develop their skills and confidence as inquiry facilitators capable of guiding students through their own investigations. Diversions from lesson plans, incorrect results from experiments and concerns as to the level of guidance required for student success are common challenges when implementing an inquiry-based approach to science education (Trautmann et al 2012; Yoon, Joung and Kim 2012). Using citizen science as the initial structure for inquiry activities can also scaffold teachers in the development of their knowledge, skills and confidence as inquiry facilitators.

Classroom activities to supplement the NS3 Intertidal Monitoring project were designed so that students could apply what they had learned from the citizen science experience. After exploring the new provincial curriculum and determining the practical needs of teachers, we chose to concentrate on the concept of a scientific protocol. Activities focused on just a few of the phases of inquiry: orientation to a problem, planning an investigation and communication of a research plan. As previously described, students were asked to design a monitoring protocol and create a video to pitch their research idea to a granting agency to fund their research. Scaffolding, in the form of prompts, suggestions and discussion, occurred throughout, particularly when it came to the generation of a scientific monitoring protocol. Reference to the protocol used in the intertidal monitoring citizen science project also occurred numerous times to provide context. While the exercise did not have students generate their own research questions or hypotheses (the focus was monitoring), and the students did not actually conduct the investigations (which they found disappointing!), it very much aligned with the work of a professional scientist. This gave the activity authenticity, as did the fact that groups were presenting to an audience of peers, educators and scientists to receive funding for their research. While groups received only play money, the excitement at receiving it indicated the value of having the communication component of this activity judged.

This example shows that citizen science, while often a structured form of inquiry, can provide students with the initial opportunity to become engaged in the process of scientific inquiry due to its authenticity and relevance. Citizen science research clearly models the scientific inquiry process for students, and provides students a meaningful opportunity to act like scientists and better understand their ways of knowing. This lived experience can then be applied to inquiry-based learning activities in the classroom that allow more student control. Teachers can choose to focus on just some of the inquiry phases, as described in the NS3 Intertidal Monitoring project, or use the experience as a "question engine – an activity that engages students in making observations and inferences as a precursor to generating research questions" to begin their own investigations (Tomasek 2006, 206). Either way, the physical, personal and social context provided by the authentic citizen science experience will contribute to the next iterations of inquiry learning. As a result, participation in citizen science should be considered as a means to support classrooms as inquiry-based learning environments.

While the NS3 Intertidal Monitoring case study may be more representative of a local scientist–teacher–student partnership (STSP) (Zoellick, Nelson and Schauffler 2012), many web-based citizen science projects are also capable of offering substantial support for teachers and students in fostering inquiry in the classroom. For example, eBird is a well-known citizen science project, designed by the Cornell Lab of Ornithology, that collects data on the abundance and distribution of birds in the form of online birding checklists. eBird provides web-based visualization tools to explore the data in a multitude of formats, which can provide an excellent platform for students to engage in the generation of their own scientific questions (Tomasek 2006). To support teachers and students through the inquiry phases, they also developed BirdSleuth, which provides free lesson plans and teacher guides that focus on investigating evidence through all phases of the inquiry process. Professional development opportunities and discussion forums for teachers are also available, as well as a platform for students to present their results, all of which support the facilitation of student inquiry. Journey North is a global study of wildlife migration and season change that has a teacher guide specifically designed for building inquiry into instruction. Resources to support teachers continue to evolve as teams of science educators contribute to the design of projects to increase their educational value for participants.

Where Does a Teacher Start?

The massive increase in citizen science projects worldwide means there are a variety of established projects available to meet the different needs and goals of educators. Specific to Alberta, Nature Alberta recently released a report that includes an appendix listing 89 citizen science projects (Nature Alberta 2013). SciStarter and the Cornell Lab of Ornithology's Citizen Science Central both offer a searchable database of citizen science projects that can be searched by scientific topic, activity and/or location.

An excellent resource for teachers entitled *Citizen Science: 15 Lessons That Bring Biology to Life, 6-12* (Trautmann et al 2013), provides inquiry curriculum to support established citizen science projects such as eBird, Journey North, the Lost Ladybug Project, Project FeederWatch, YardMap, the Whale Song Project, FrogWatch, the World Water Monitoring Challenge and Project Squirrel. For each lesson there is a brief overview of the research, learning objectives, time and resource lists, worksheets, and guidelines on how to lead students through the inquiry phases of the 5E instructional model: engagement, exploration, explanation, elaboration, and evaluation (Bybee 2009). While some lessons are based on citizen science projects targeting the United States, many are international projects and others have Canadian equivalents.

The NS3 Intertidal Monitoring citizen science project described in this article is more representative of direct collaboration between scientists and educators, because the project is in its infancy. This type of collaboration can be very powerful in fostering a culture of inquiry in the classroom, but it should be noted that it will take time to develop these types of relationships. Universities, science centres, museums, zoos, environmental agencies, recovery centres and even government agencies are all ideal for connecting with scientists that might be interested in a scientist–teacher–student partnership.

Conclusion

Evidence of the educational value of citizen science continues to accumulate as new tools and resources are developed in an effort to enhance engagement and the scientific literacy of the general public. This, along with the call for a more inquiry-based approach to learning, has meant that citizen science represents a valued approach to science education. As a result, citizen science is increasingly being explored as a means to support student inquiry in the formal K–12 classroom. An introduction to the NS3 Intertidal Monitoring project and recent literature both support the idea that participation in citizen science can scaffold teachers and students through the transition of classrooms into more inquiry-based learning environments. For students, participation in citizen science provides orientation to a real-world problem and naturally engages them in the scientific process through its relevance. The opportunity to participate in authentic scientific research with a physical, social and personal context has great potential to develop a deeper, more conceptual understanding of scientific content and processes. For teachers, participation in citizen science provides the opportunity to build proficiency in their new role as inquiry facilitators. As students and teachers develop their inquiry readiness, the scaffolds provided by citizen science can fade to allow for a more open approach to inquiry, in which students construct their own knowledge through personal investigations and discovery.

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Creating an Engaging Science Inquiry Activity for Middle School Students That Incorporates Online Remote Access to Analytical Instrumentation

Nikki Stewart, Susan Lidster, Tory Anchikoski, Bruno Cinel, Sharon Brewer and Carol Rees

Introduction

The decline in young peoples' interest in science and technology education and the reduction in the proportion of students choosing to pursue careers in science and technology have been causing concern internationally for over a decade (OECD 2006). It is known that young people's attitudes to science and technology are usually established early in life and that efforts to encourage interest and build awareness are best targeted toward middle school students (DeWitt, Archer and Osborne 2014; Riegle-Crumb, Moore and Ramos-Wada 2010). This context prompted three initiatives that came together to create the learning opportunity for middle school students evaluated in the pilot study described in this paper. In the context of their inquiry project, the Grade 8 class worked with science professionals to remotely use an instrument in the university chemistry lab to analyze river water samples for total nitrogen. A pilot study of the initiative that examined students' responses to survey questions using the lens of *productive disciplinary engagement* (Engle and Conant 2002) indicated high levels of student engagement, specifically in the discipline of science, that were productive in advancing their learning of science and awareness of the actual practices that science professionals use. At the end of the paper, these findings are corroborated and expanded upon by the teacher in her reflections. Further work will look at how this productive disciplinary engagement develops, by analyzing video recordings of students, teachers and scientists interacting within this collaborative venture.

The Three Initiatives

1) **A Cross-Curricular Inquiry (CCI) Program for Grade 8 Students Cocreated by a Teacher/Principal Team in Response to the New British Columbia Curriculum**

Science education reform recommendations globally, including those in British Columbia, recommend shifting to a more inquiry- and project-based approach (British Columbia Ministry of Education 2012; Next Generation Science Standards 2013; Rocard et al 2007; Tytler 2007). In response to the new British Columbia K–12 curriculum, a teacher and principal at a southern interior British Columbia middle school cocreated a cross-curricular inquiry program (CCI) for Grade 8 students. Twenty-five self-selected students enrolled in the program and met from 8:30 AM to 3:00 PM every second day to engage in project-based learning that encompassed the curricular competencies of science, social studies and English language arts.

The class theme for the year, What Sustains Us, began with a study of water and the driving question: How can we create a potable water solution for an off-the-grid community? The class created a fictitious off-the-grid community, learned about the importance of and concerns surrounding access to clean drinking water, and researched different water treatment methods. Students also hypothesized the optimal location of the off-the-grid community along a local river. As Grade 8 students considered water treatment options, they began to question the optimal location for their off-the-grid community. Questions varied about topics such as water quality and the effects of geological and man-made features along the local river. Students also expressed an interest in testing water samples.

To increase engagement and real-world connections for students during their study of water, the school principal and classroom teacher approached faculty in the School of Education at a local university who were working on partnerships with faculty from multiple disciplines at the university in a network called the K-16 Research and Development Network.

2) **The K-16 Research and Development Network (K-16RDN) in Education Develops and Investigates Projects Linking School and University**

The K-16 Research and Development Network is a partnership between a university in British Columbia and a local school district. The K-16 initiative looks at education as a continuous journey from kindergarten all the way through to the completion of a degree. The initiative brings together teachers from the school district and faculty from various disciplines at the university to work on projects that introduce faculty expertise to K–12 classrooms. Faculty and teachers collaborated, planning projects together around the faculty members' disciplines. This provided an opportunity for secondary school students to deepen their understanding of what it means to study and work in the chosen discipline. Through these projects, students developed their skills in collaboration, creativity, innovation and communication. These are skills that benefited them in their learning in secondary school, in their transition to postsecondary education and in their success in the workplace.

The teacher and principal who cocreated the CCI program approached members of the K-16 Research and Development Network (K-16RDN), seeking partnerships with science faculty interested in the What Sustains Us project. A collaboration ensued with the chemistry faculty members who created the British Columbia-Integrated Laboratory Network (BC-ILN).

3) **The BC-Integrated Laboratory Network (BC-ILN) Has Been Providing Online Remote Access to Analytical Instrumentation in University Chemistry Labs for the Past 10 Years**

The BC-ILN is a project that provides online remote access to cyber-enabled scientific analytical instrumentation, instructional materials and expertise to enhance student opportunities in science education. Students that access remote instruments for chemical analysis manipulate and control real laboratory equipment and generate data from real samples; however, these students are physically separated from the lab and control the equipment over the Internet (Erasmus, Brewer and Cinel 2015; Kennepohl et al 2005; Ma and Nickerson 2006; Crippin, Archambault and Kern 2013).

Bringing the Three Initiatives Together

This collaboration between the CCI, K-16RDN and the BC-ILN involved creating a new, interactive, multiday student learning activity called Measuring the Total Nitrogen Content of River Water Samples (see Table 1), using educational resources previously developed by the BC-ILN (www.bciln.ca). Given the CCI focus and interest in water, a previously developed BC-ILN activity, Water's the Matter?! (Candow 2013), in which users determine total nitrogen (TN) levels present in water samples from select sites around a lake, was modified to a river scenario in consultation with the classroom teacher. New instructional materials including videos, an interactive poster and analysis instructions were created.

Table 1 below summarizes the three-day student learning activity, Measuring the Total Nitrogen Content of River Water Samples.

Accessing the Analytical Instrument Remotely

The instrument used to analyze water samples was a Shimadzu TOC-V/TN Analyzer controlled by a computer connected to the Internet. This modified activity aligned with the students' interest in determining, as a part of their project, the best location to situate a community along a river to ensure potable water. It augmented other work that students were doing on water quality. The sample sites created along the fictional river were chosen to consist of locations the students and their teacher had identified as potentially influencing water quality.

Samples corresponding to water obtained from the different locations on the fictional river were placed in vials and loaded into the instrument's autosampler at assigned positions. The software program Teamviewer (www.teamviewer.com) was then used to allow the students to remotely connect to the TN analyzer's computer and operate the instrument from a laptop

Day 1:	Introduction to Nitrogen and Its Potential Impact on Water Quality (1 hour)	
	Students watched a video about nitrogen, explored websites to answer questions about nitrogen and its effects on plant and animal life, participated in a nitrogen cycle game, and learned about some local research on the biological effects of algae blooms on amphibians.	
Day 2:	Introduction to Total Nitrogen, Instrumentation, and Fictitious River (1 hour)	
	1. Students were divided into groups of three, with each group representing a location along the river: wastewater treatment plant, small farm, campground, big farm, construction site, creek and middle of the river. 2. Students were introduced to the definition of total nitrogen. 3. Students watched the video *BC-ILN: How to Perform a Sample Analysis for Total Nitrogen*[1] and interacted with the university's chemistry lab through the touch screen tablet. 4. Groups used the interactive map[2] highlighting the seven points along the fictitious river and additional websites to research the potential effects of each location on nitrogen levels. 5. Groups used their research to rank the locations from highest predicted TN level to lowest predicted TN level. All groups recorded their predictions on a poster.	
Day 3:	Testing Total Nitrogen, Collecting, and Interpreting Data (2 hours) Working in the same groups as day 2, students visited six stations.	
	Station 1	Groups used the BC-ILN to test their water sample and record TN results.
	Station 2	Groups added the results of their TN test to a large bar graph.
	Station 3	Students watched BC-ILN- A video tour of the Total Nitrogen (TN) Analyzer[3] and answered questions about the TOC-V instrument.
	Station 4	As data was recorded, groups changed their predictions from day 1.
	Station 5	Using Google Maps and their own knowledge of the rivers, students located an area along the river similar to theirs and labelled it on a large map.
	Station 6	Groups coloured clipart images to represent their part of the river on the bar graph and on the map of the rivers.

Table 1. *Summary of the Three-Day Student Learning Activity: Measuring the Total Nitrogen Content of River Water Samples*

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[1] https://www.youtube.com/watch?v=TVZoFI0vpHE (accessed September 12, 2017)

[2] http://edu.glogster.com/glog/bc-iln-activity-waters-the-matter-investigate-river-water-qual/2l3n0tk9xrv (accessed September 12, 2017)

[3] http://edu.glogster.com/glog/bc-iln-activity-waters-the-matter-investigate-river-water-qual/2l3n0tk9xrv (accessed September 12, 2017)

at their school. In addition, students could also view the interior of the instrument's autosampler carousel from the laptop via a Microsoft LifeCam VX-1000 (which was mounted in the instrument). In the university laboratory, a ceiling-mounted Canon VB-C50iR network camera allowed students to view both the instrument and laboratory using a touch screen tablet. Students could control the ceiling-mounted camera via the tablet to view and zoom in on any particular part of the instrument at will. Audio and visual communication between the students and a faculty member at the university was facilitated with Skype (www.skype.com).

When performing the water sample analysis part of the activity, students in groups of three would input their sample name using the instrument software, select the autosampler position for their sample and start the analysis. They would then observe the acquisition of data from their chosen sample in real time via the remote connection to the instrument computer, as well as hear and see the instrument in action using the cameras and microphone. Throughout the remote analysis and data acquisition, the students could interact directly with an instructor present with them or with the instrument technician at the university via Skype. At the end of the analysis, the TN level present in the water sample was determined and students recorded their results on a class graph that combined the class data obtained from all groups.

The Pilot Study

Theoretical Framework

This study focuses on engagement according to Engle and Conant's (2002) definition of *productive disciplinary engagement*. According to this definition, *engagement* includes general engagement (*engagement*), relevance to the discipline (*disciplinary engagement*), and the development of understanding (*productive disciplinary engagement*). Although Engle and Conant (2002) were using this definition in their study of classroom discourse, in this study it is applied to the analysis of students' responses to survey questions. The reason that this definition was chosen is that the researchers were interested not only in *engagement* in the BC-ILN experience, but also in how this experience led to *engagement in the discipline* of science and the *productive* learning of students. The pilot study survey questions have the capacity to show evidence of the students' engagement through the expression of their level of enjoyment, their level of interest in the disciplinary knowledge or their view of the extent of their learning.

Research Question

Based upon the definition above, the research question that we addressed in relation to the collaborative activity Measuring the Total Nitrogen Content of River Water Samples is, How would we characterize student engagement in the collaborative activity Measuring the Total Nitrogen Content of River Water Samples?

Methods

All 25 Grade 8 students in the class were invited to participate in the pilot study following procedures approved by the university ethics board for research involving human participants, and by the school district. Eighteen students and their parents or guardians agreed to participate by completing the survey on day three, after completion of the activity.

This survey instrument was developed from surveys previously reported in the literature that evaluated student engagement (Carle, Jaffe and Miller 2009; Ouimet and Smallwood 2005) and learning chemistry (Barbera et al 2008), together with studies that specifically focused on science laboratories (Domin 1999; Corter et al 2011). The survey instrument had 14 questions total: 13 four-level Likert scale questions and one open-ended question to allow students to comment on any aspect of the remote analysis experience. Using the productive disciplinary engagement framework outlined in the "Theoretical Framework" section above, the 13 Likert scale questions (Table 2) were characterized as follows: those that focus on engagement in general (questions 4 and 5), those that focus on disciplinary engagement (questions 1, 2, 3, 6, 7, 10, 12 and 13), and those that focus on productive disciplinary engagement (questions 8, 9 and 11). This productive disciplinary engagement framework was also used to categorize the students' responses to the open-ended question (Table 3).

	Likert category response frequency				Theoretical classification		
Question	Not Very Enjoyable	Somewhat Enjoyable	Enjoyable	Very Enjoyable	Engaging	Discipline	Productive
1. Overall, how enjoyable was the TRU online laboratory activity?	0	3	7	7	X	X	
2. How enjoyable was it working with real samples?	0	2	5	10	X	X	
3. How enjoyable was it using the instrument to do chemical analysis?	0	4	2	11	X	X	
4. How enjoyable was it communicating by Skype with TRU?	1	4	4	8	X		
5. How enjoyable was it controlling the camera?	1	1	5	10	X		
6. How enjoyable was it controlling the instrument?	0	1	6	10	X	X	
	Never/ Rarely	Sometimes	Often	Very Often			
7. How often were you actively participating in the TRU online laboratory activity?	1	5	5	6	X	X	
	Very Little	Some	Quite a Bit	Very Much			
8. To what extent did the TRU online laboratory activity help you understand chemistry concepts?	1	5	7	4	X	X	X
9. To what extent did you understand the learning objectives of TRU online laboratory activity?	1	3	9	4	X	X	X
10. To what extent did the TRU online laboratory activity make you want to continue on in science?	3	1	4	9	X	X	
11. To what extent did the TRU online laboratory activity provide you with an understanding of what it is like to do real science?	0	1	8	8	X	X	X
	Not Very Relevant	Somewhat Relevant	Quite Relevant	Very Relevant			
12. How relevant was the TRU online laboratory activity?	0	3	5	9	X	X	
	Not Very Engaging	Somewhat Engaging	Quite Engaging	Very Engaging			
13. How engaging was the TRU online laboratory activity?	1	3	5	8	X	X	
n=17							

Table 2. Pilot Study Survey Questions, Responses and Theoretical Classification

Results

The responses to the Likert scale questions and the open-ended question indicated that the majority of students who responded found high levels of engagement in the online laboratory. In Table 2, questions 4 and 5 focus on general engagement or enjoyment that is not disciplinary. Responses to question 4 indicate that 12 of 17 students found it enjoyable or very enjoyable to communicate by Skype, and 15 of 17 found controlling the camera enjoyable. These responses indicate that most students found engaging with the technology to be enjoyable. This finding is corroborated by the first response to the open-ended pilot study survey question, "It was fun, I liked controlling the camera" (Table 3).

Responses to Likert scale questions 1, 2, 3, 6, 7, 10, 12, and 13 (Table 2) and open-ended question responses 4, 6, 7 and 8 (Table 3) demonstrate students' disciplinary engagement (engagement in the discipline of science). Questions 1 and 13 are very

Open-ended question: Any comments you would like to make on your experience using the instrument over the web to do the TRU online laboratory activity?			
Responses	Theoretical classification		
	Engaging	Disciplinary	Productive
1. It was fun, I liked controlling the camera. But only 1 person got to sit at the computer and control what was happening.	X		
2. I think this hands-on learning activity is an excellent way to learn new concepts and to spark interest in science in young individuals.	X	X	X
3. Thank you so much for coming in to our class and showing us how nitrogen samples are tested.	X	X	X
4. I loved getting to have access to a new and accurate resource.	X	X	
5. :)	X		
6. I have always wanted to do stuff like this and now I have!	X	X	
7. It was very cool for them to come down to [our school] to do science with us.	X	X	
8. It was interesting to see how the instrument worked.	X	X	

Table 3. Pilot Survey Open-Ended Question, Responses and Theoretical Classification

similar, and responses demonstrate high levels of disciplinary engagement in that it was specifically the laboratory activity that 14 of 17 students (question 1) and 13 of 17 students (question 13) found enjoyable or engaging. Questions 3 and 6 are also similar—both refer to enjoyment level of using the instrument; question 3 refers to using the instrument to do chemical analysis, while question 6 refers to controlling the instrument. Results indicate that 13 of 17 students enjoyed using the instrument to do chemical analysis and 16 of 17 students enjoyed controlling the instrument. Additionally, two of the responses to the open-ended question reflect students' enjoyment of access to the science resources including the instrument (response four, "I loved getting to have access to a new and accurate resource," and response eight, "It was interesting to see how the instrument worked").

Responses to question 2 indicate that 15 of 17 students found it enjoyable to work with real samples. Interestingly, 14 of 17 students found the laboratory activity relevant (question 12). One interpretation of "relevance" in question 12 could be relevance to real life. These two sets of responses could also indicate that students' enjoyment is enhanced by real-life examples. This could further relate to question 7, indicating excitement that real scientists had visited the school.

Question 7 elicited findings that could be useful in future iterations of the project. Interestingly, only 11 of 17 students indicated that they were actively participating in the online laboratory activity. One possible explanation is that the students were placed in groups of three and there was one laptop (to control the instrument) and one tablet (to control the camera). Therefore, at any one time, only two students had hands-on control of the instrument or camera; therefore, one of the group members could have felt that they had not participated directly in the project. In the responses to question 10, 13 of 17 students indicated that the laboratory activity encouraged them to continue in science.

Questions 8 and 9 are similar in that they ask students about how the online laboratory activity affected their learning (productive disciplinary engagement). Question 8 refers to their learning of chemistry concepts, and question 9 refers to the learning objectives of the activity. Findings (Table 2) show that 11 of 17 students indicated that the online laboratory activity helped them understand laboratory concepts, and 13 of 17 indicated that they understood the objectives of the online laboratory activity. This was further supported by two of the responses to the open-ended question:

- "I think this hands-on learning activity is an excellent way to learn new concepts and to spark interest in science in young individuals" (response two)
- "Thank you so much for coming in to our class and showing us how nitrogen sample are tested") (response three)

Since the chemical concepts and learning objectives refer to measuring the amount of nitrogen in water, it is interesting to note that not all students indicated that the activity helped them with learning the objectives. Students were learning about the importance of nitrogen in water in other ways, such as online information searches of text and video. This result could indicate that some students found these ways of learning more useful than interacting with the instrument. Fascinatingly, responses to question 11 indicate that 16 of 17 students found that the online laboratory activity helped them to understand what it is like to do real science. This supports the overall initiative of the collaborating teams (CCI, K-16RDN, and BC-ILN).

Teacher Reflection

The classroom teacher made several key observations that supported our preliminary results. Anecdotally, the teacher noted increased levels of engagement of particular students during the project. The teacher reported that students who typically engaged in class activities were equally engaged in the online remote access experience. More notable were the increased engagement levels of students who typically struggled with traditional class work. The teacher recalled that during a 20-minute recess break, some students stayed in the class and "played" with the touch screen camera control and engaged in conversations with the laboratory technician at the university via Skype.

Following the activities on day 3, the classroom teacher asked students to answer additional informal feedback questions. Students used Chromebooks to submit their answers to the questions, What did you like about using the remote lab? What did you not like about using the remote lab? and What did you find interesting/surprising about the experience? Students were asked to answer candidly and were assured their feedback was not for marks. Every student participated in the feedback, and the teacher received 59 electronic, full-sentence responses. This is in stark contrast to the 8 handwritten responses to the open-ended question collected in the pilot project. The high participation rate for the teacher activity may be explained by the students' belief that teacher-assigned work must be completed to specific standards; however, other explanations may be the use of technology to collect information, or that students did not put as much effort into the pilot study survey because it was assigned immediately after the teacher-assigned questions. The questions asked in this informal feedback were not part of the ethics approval for this study; however, we will consider asking similar questions in future studies and use electronic collection methods.

Answers to these questions reflected themes similar to those found in the pilot study survey. Students demonstrated productive disciplinary engagement when they reported their learning about nitrogen in water. This is indicated in comments such as they liked "real accurate information that we didn't just find on the internet" and "how we got to see the total nitrogen in the samples." Several reported surprise at the results of the lab. One student commented that "there was more nitrogen in the river water near a small farm than the river water near a big farm," and even more students commented on how amazing it was to control the instrument remotely and watch the results in real time.

The teacher questions also revealed that some students felt left out during the water test, and enjoyment of the activity was reduced for some students who did not actively operate the remote equipment. These responses may partly explain the results of question 7 (Table 2) in the pilot study survey. We might infer that students' interpretation of *actively participating* means hands-on participation; consequently, a group of three students at a station with only two pieces of equipment could result in one-third of all students feeling less engaged.

The new British Columbia curriculum states that "The integration of areas of learning and technology also have opened the door for teachers and schools to approach the use of time and space in creative ways …" (British Columbia Ministry of Education 2012). It should be noted that the classroom teacher was not a science specialist. For this reason, the teacher sought out creative partnerships that would open doors to rich learning experiences for students in the program. Collaboration with the university to create this experience for students extended beyond using the Integrated Laboratory Network: faculty worked alongside the classroom teacher to intentionally support the students' existing study of water, and to create tools—like the interactive poster—that were accessible to all members of the class. The classroom teacher advocated for the students' needs, and faculty adapted their existing resources to suit the new audience. The result was a three-day student learning activity tailored to the class and their ongoing research. Overall, the classroom teacher was pleased with the learning and levels of engagement for students and is keen to do a similar project in future years.

Conclusions

Applying the theoretical framework of productive disciplinary engagement to the results of the survey was useful in that it allowed us to categorize student responses. From this, we were able to see that through the activity students were highly engaged in the discipline of science and that this engagement was productive in advancing the students' learning.

Limitations of the study were that (a) this was a pilot study with a small number of students in only one classroom; (b) the pilot study survey questions ask only about level of enjoyment in specific aspects of the activity, so it is difficult to know precisely what students found engaging; and (c) the study focused on students' impressions of their engagement and learning rather than direct observation.

Further research could include (a) more participants and classroom groups, (b) student interviews to allow expansion of feedback and (c) direct observation using video recording and analysis of the activity. Providing online hands-on access to scientific instrumentation for curriculum-appropriate investigations could be an effective and economical way to engage students in remote and rural communities. This pilot study indicates the power of the approach to support students' engagement and learning in the discipline of science.

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Promoting Scientific Literacy Through the Use of Adapted Primary Literature in Secondary Science

Hyacinth Schaeffer and Bonnie Shapiro

The Need for New Approaches

In this article we present a discussion designed to help educators consider the value of a strategy to enhance secondary students' science knowledge and a teaching approach that introduces students to primary scientific research. The article is based on research recently conducted during a professional development program designed to introduce secondary science teachers to a new teaching strategy that involved the introduction of adapted primary literature (APL) as a teaching tool (Schaeffer 2016). We introduce the article by first reviewing current thinking about the meaning and importance of developing scientific literacy in secondary classrooms, then present an argument for the consideration of APL as a potentially valuable approach.

Like many science programs worldwide, secondary science programs of study in Alberta are "guided by the vision that all students have the opportunity to develop scientific literacy" (Alberta Education 2005, 1). The programs further describe the knowledge, skills, and attributes that students must develop in order to attain a level of scientific literacy that is personally and socially relevant. Although the term *scientific literacy* is a commonly used term in STEM (science, technology, engineering and mathematics) education, it is useful to acknowledge that developing scientific literacy involves complex thinking skills that must be explicitly taught and practised by both teachers and students. Above all, a common understanding of what scientific literacy entails is essential. Cavagnetto (2010) explains that

> Scientific literacy is the ability to accurately and effectively interpret and construct science-based ideas in the popular media and everyday contexts. As such, scientific literacy is realized by an understanding of scientific principles, processes, and argument, all of which are supported by cognitive and metacognitive processes as well as critical reasoning and communication skills … [it] requires the abilities and background understandings to interpret meaning from text, talk and other modes of representations to build new interpretations. (pp 352–53)

This definition implies that simply knowing facts and being able to work through a set of predetermined processes are not enough to be considered a scientifically literate citizen. It further suggests that students must also be able to actively engage in examining and discussing the claims offered by the scientific community, particularly those they encounter in their studies. When students are encouraged to analyze and defend or refute their own and others' interpretations, they are engaging in critical thinking and argumentation, both important attributes in the development of scientific literacy.

Gunn, Grigg and Pomahac (2008) refer to critical thinking as the "intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication" (p 168). Additionally, researchers suggest that the ability to engage in scientific argumentation, or the use of evidence to support claims, is central to negotiating meaning and advancing knowledge, not only in science but also across disciplines (Hand et al 2009; Cavagnetto 2010). Analyzing the ways in which scientists develop and support their arguments offers students an authentic view of the processes of science and represents an opportunity that may not present itself to students through the use of traditional learning resources.

As one approach to developing critical thinking, Yarden (2009) has proposed that having students review and discuss current and relevant research articles may provide a bridge between "scientists' science" and "school science" by illuminating the investigator's processes and arguments. Many thinkers argue that textbooks alone may not reveal the journey and persistence of scientists that eventually lead to generally accepted understandings (Barker and Julien 2012; Brill, Falk and Yarden 2004; Norris and Phillips 2003; Yarden 2009). Traditional classroom resources are often written for students, while scientific research, in its original form, is written for experts in a particular field of study. How, then, can the authenticity of a scientist's work be presented in a manner that novices can understand, reflect upon and discuss? One approach may be to use APL written specifically for secondary science students. Schaeffer's (2016) review of research literature examines a variety of formats in which scientific research can be found and readily used in classroom settings. This review provides an interpretive context for a research study undertaken of a professional development program that introduced educators to APL. Insights into teachers' experiences were gained through interviews conducted with participants in a scientist–teacher partnership that focused on the development of APL articles for use in secondary science instruction with the purpose of involving students in thinking critically about scientific research.

Scientific Information and Research

Primary scientific literature (PSL) refers to research articles that are written by scientists for their colleagues in peer-reviewed journals. Typically, these articles are highly technical and geared to the research audience in the same or related fields and therefore are usually not easily accessible to or understandable by the general public. Journalistic reported versions (JRV), found in popular media, are written by science journalists and often provide truncated claims without the support of data and reasoning for the scientist's interpretations. An argument for the claims, based on evidence from the investigation, is often missing (Brill, Falk and Yarden 2004; Yarden 2009). Adapted primary literature (APL) is a novel text genre written to maintain the critical features of PSL, including explanations of the problem and investigative processes used, evidence to support claims made by the researcher, and scientists' interpretations of the data (Shanahan 2012; Yarden 2009). As such, APL offers students access to authentic science presented in language that is accessible to them and supported with graphics, tables and charts to illustrate concepts, results and interpretations. APL has the potential to bring current and relevant science into the classroom in a way that other primary and secondary sources typically cannot (Cervetti and Pearson 2012; Falk and Yarden 2009; Norris et al 2009). Arguably, APL is as authentic as PSL (Yarden, Norris and Phillips 2015) because it is written by scientists with the added pedagogical expertise of teachers, making it worthy of consideration as an alternative learning resource in secondary school science instruction. Norris et al (2009) propose that each form of text has its own unique and important role to play in promoting scientific literacy, and one should not replace another. They assert that careful consideration of the purpose and the audience will determine the best choice of resource.

Making a Case for APL in Classroom Instruction

Field and Powell (2001) argue that definitions of scientific literacy have not included the importance of public understanding of research, distinguishing it from public understanding of science. They say

> The current world research agenda is comprehensive. The results of many studies and experiments in which scientists are currently engaged will undoubtedly have profound impacts on the lives of citizens in developed and developing nations. Yet few people even know what research is being conducted; much less understand why it is being done and what the potential implications may be. (Field and Powell 2001, 421)

In order for citizens to be able to participate fully in public discussions surrounding emerging issues in areas such as biotechnologies and climate change, they will benefit from understanding how and why scientific research is conducted (Miller 2004). In preparation for this, we suggest that students must be involved in their own problem solving and inquiry and also engage with the published work of experts in the field.

APL offers one avenue for exposing students to authentic scientific investigations (Falk and Yarden 2009) while opening a discussion about the purpose, procedures and ethics involved in research. APL has the potential to reveal the ways in which scientists work, but also to shed light on the thinking, perseverance, patience and hard work that are required in the process of building new understandings. It also provides fodder for discussion about why and how scientists determine appropriate procedures and make interpretations from the data, thus involving students in the skills and processes of critical thought. Through the use of APL as a learning resource, students may experience science in action and learn to view reading as one form of inquiry. This approach supports the development of literacy across disciplines and an appreciation of the groundbreaking work that is being accomplished in local, national and global communities.

The Research Project

The January 2011 issue of the *Alberta Science Education Journal* featured an article entitled "Using Adapted Primary Literature to Teach High School Science" (Stelnicki et al 2011), in which the authors argued that the use of current scientific literature as an instructional resource in an experimental project promoted critical thinking in students. Their claim is of interest if the ability to think critically is considered foundational to developing scientific literacy (Vieira and Tenreiro-Vieira 2016). Although most curriculum materials used in secondary science programs do not explicitly identify the use of primary sources of research in instruction, philosophical statements that underlie the goals of science education typically include expectations that can be well addressed through the utilization of APL as a learning resource. For example, in the Alberta science programs of study, foundation 1 states that students will understand the nature of science and the interrelationships between science and technology within social and environmental contexts (Alberta Education 2005, 3). Critiquing current research reveals not only the nature of science but also how and why the work is important within social and technological contexts. Students are able to draw on their examination of the work of others when they are called upon to design their own investigations.

Foundation 3, focused on skill development, indicates that students will develop the skills required for "communicating scientific ideas and results" (Alberta Education 2005, 3). These outcomes can be illustrated through exposure to scientific literature supplemented with meaningful discussion and personal investigations. Communicating about their own inquiries, results and interpretations can be modelled against the arguments made by professional scientists, technologists and engineers.

If the use of APL in science instruction has the potential of promoting critical thinking in students, thereby supporting the development of scientific literacy, then it follows that encouraging teachers to learn about and engage with authentic text may be considered a worthwhile endeavour. In 2011, as part of a larger initiative, a teacher professional learning experience was introduced through a partnership between the Canadian chapter of the Scientific Research Society (Sigma Xi), the University of Calgary faculties of Science and Education, and local school jurisdictions. The goal of the partnership was to develop APL articles through the interaction between local teachers and the principal investigators of published scientific literature. The resultant APL articles were designed to be used in secondary science instruction. The professional learning program, which ran over three academic years, involved a total of sixteen teachers from two publicly funded school districts along with three scientists and four science graduate students. The program, named Sigma Xi Research Connections (www.bgs.ucalgary.ca/education/programs_research-outreach#sigma), became the subject of a graduate research project (Schaeffer 2016) that informs this article. Utilizing participant interview data, observation and extensive field notes, teachers' experiences and post-experiences with the professional development program were documented and interpreted. Results and recommendations from the study are included in this article.

APL in the Classroom: Opportunities and Challenges

The opportunities presented by APL are many but there are also challenges, not the least of which are the time and expertise required to develop useful articles from primary research and to rethink instructional strategies to incorporate novel resources. Based on work to help practising educators implement APL resources, we learned first-hand that adapting primary scientific literature is not a simple task. It requires the expertise of scientists and teachers, and the content must be related directly to learning outcomes in the program of studies if it is to be useful in instruction. Juggling the limited minutes allocated to science instruction means that traditional approaches and resources must be substituted with APL articles and discussion, a substitution that is not readily acceptable without proof of its merit. In addition, this adjustment represents a significant change in practice and requires new thinking and approaches. Adopting an innovative mindset (Couros 2015) can make it possible, while at the same time paying attention to the prescribed learning outcomes and seizing opportunities to develop the critical reasoning skills that are required for accessing content knowledge.

Pilot projects employing APL articles and stories have been tested in Alberta and other jurisdictions (Norris et al 2009; Phillips and Norris 2009; Schaeffer 2016; Shanahan 2012; Stelnicki et al 2011; Yarden, Norris and Phillips 2015), and based on positive results of student learning, the use of APL is now embedded in the national science curriculum in Israel (Baram-Tsabari and Yarden 2005; Yarden, Brill and Falk 2001). Exemplars from these studies show that not only are students capable of interacting with complex text, but they and their teachers develop new insights and curiosity to fuel their own investigations that support continued learning.

Introducing APL to Students

There are obvious distinctions between the level of inquiry that is conducted by scientists and that which is possible for secondary students (Lee and Butler 2003). Combining first-hand student inquiry with second-hand inquiry through reading and discussing APL has the potential to provide students and teachers with a more complete and authentic experience of the scientific endeavour.

Analysis of the data collected from teachers who participated in the Sigma Xi Research Connections professional development program indicates that they were eager to expand their own learning with regard to new research directions and valued their interactions with scientists and science graduate students (Schaeffer 2016). Outlined here are many lessons that were learned about assisting teachers with the implementation of APL programs. Working within highly structured timetables and curricular expectations introduced certain obstacles that prevented some from utilizing the APL articles that were developed in the workshop sessions. Among the most common challenges were the lack of time to plan for and incorporate APL in instruction and the need to teach or reinforce basic literacy skills that science teachers felt unprepared to do (Schaeffer 2016). One way that we suggest will help address these concerns is to develop a library of relevant APL articles correlated to curricular topics and learning outcomes that may be readily accessed by educators, removing the time required to produce appropriate articles by individual teachers. The preparation of such articles requires the expertise of teachers and scientists working together to ensure accuracy of information, appropriate correlation to curricular learning outcomes and sound pedagogy. In addition, science teachers will benefit from further professional development experiences that provide reading-to-learn strategies to support students as they navigate a novel text genre that will be new to everyone.

In environments where introducing APL was successful, teachers identified the following structures, attitudes and resources as facilitating factors: (1) support from administration, colleagues, and parents; (2) a willingness from teachers to be innovative in their practice with the goal of improving students' experiences in science; and (3) conceptualizing the project as an opportunity to address foundational statements provided in curriculum documents that guide learning such as those described by Alberta Education (2005, 3). Schaeffer's (2016) work reveals that when teachers consider APL in the larger context of literacy across disciplines, or as a cross-curricular competency, they are better able to incorporate the resource in their classroom practice. The Edmonton Regional Learning Consortium defines cross-curricular learning competencies as follows:

> A cross-curricular competency is an interrelated set of attitudes, skills and knowledge that are drawn upon and applied to a particular context for successful learning and living. They are developed by every student, in every grade and across every subject/discipline area. (http://erlc.ca/resources/resources/cross_curricular_competencies_overview/documents/cross_curricular_comptencies_overview.pdf)

Reading as an inquiry process is a competency that is useful across disciplines and adds to a student's ability to negotiate meaning and improve learning. In summary, the use of APL has the potential to stimulate thought, analysis, debate and discussion, all of which are at the heart of critical thinking and the development of scientific literacy.

Resources to Support an APL-Based Program

APL is worthy of additional exploration and research as an innovative learning resource. The following examples of APL articles, available online, will give a preview into the format of APL articles for secondary science students.[1] We hope that they will assist and inspire educators who wish to begin work with APL in their classrooms.

- Coronal Heating: An Annotated Example of an Adapted Primary Literature (APL) Article
  http://link.springer.com/chapter/10.1007%2F978-94-017-9759-7_10
  This article is based on a PSL paper that addresses "the puzzling fact that the Sun's corona is much hotter than the lower layers of the Sun, which lie closer to its energy-producing core. Over the last six decades, hundreds of theoretical models to explain the corona's high temperature have been proposed. There is still no obvious solution in sight, partly because many difficulties arise in trying to understand why the corona is so hot. The original PSL article discusses ten pieces of observational evidence to support the two-step heating scenario."
- Ecology Connections
  www.ecoactionwriters.wikispaces.com/file/view/AdaptedPrimaryLit.pdf
  This monograph describes the ways in which students benefit from exposure to APL, the reasons that scientists read extensively in their field of expertise, why the peer review process is so important in scientific research, and how to begin reading PSL and APL articles.
- West Nile Virus: Mathematical Modeling to Understand and Control a Disease
  www.kcvs.ca/site/projects/modeling_files/west_nile/main%20text/westnileframeset.html
  This website provides an APL-style article that presents a mathematical model for the spread of West Nile Virus. The article can be used by teachers and students to gain an understanding of "how biological interactions are mathematically modeled."

Conclusion

This article has been presented as a resource to begin a conversation between teachers and scientists about the possible role and value of APL as a teaching and learning resource in secondary science classrooms. The value of making scientists' science more accessible to students so that they are able to develop the knowledge, skills and attributes that lead to scientific literacy is worthy of further consideration in science education. Through ongoing discussions between scientists and teachers, and continuing professional development opportunities for educators, it is our hope that discipline knowledge and pedagogical expertise can be shared through the avenue of APL for the benefit of students from high school through university.

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Students as Game Designers: Transdisciplinary Approach to STEAM Education

Beaumie Kim and Reyhaneh Bastani

Introduction

Playing and creating games for learning purposes have attracted scholarly attention for their potential to foster critical thinking skills while requiring a good understanding of concepts modelled in a game (Gee 2008). Some scholars demonstrated that students were engaged in complex systems thinking and decision making when using digital games that depict complex social–historical phenomena (eg, *Civilization*) (eg, DeVane, Durga and Squire 2010; Salen 2007). Others tasked learners with creating games, because designing games requires an integrative and holistic approach to problem solving and creating complex systems, using knowledge and skills from multiple disciplines (Hsu and Wang 2010; Salen and Zimmerman 2004, 2006). Creating digital games for learning, however, has multiple challenges. In Kafai’s (2006) work on students creating educational games, she found that learners often set the game goal of testing players’ knowledge. This showed the challenge of the learner’s understanding of good games and their perception of being “educational.” Another challenge is the learners’ programming skills. There is evidence that programming is beneficial to mathematical and computational thinking (eg, Farris and Sengupta 2016), but learning to solve complex problems through programming digital games has not shown its feasibility.

Considering these challenges, two Grade 8 teachers in a southern Alberta school implemented student design of board or card games to construct students’ understanding and competencies in STEAM (science, technology, engineering, arts and math). Learners designed games for their own learning in multiple disciplines (science, humanities, math and language arts) and for others to play and learn. This task challenged learners to create playable games that would coherently integrate and communicate their ideas. In the following article, we first explain how STEAM competencies, transdisciplinarity and game design practice correspond to each other. We suggest that designing games for learning supports learners’ transdisciplinarity to think creatively, flexibly and systematically for any discipline (Mishra, Koehler and Henriksen 2011). We then describe what the game design practice looked like in a classroom and how it demonstrated a transdisciplinary approach to STEAM learning.

Transdisciplinarity and Integrative STEAM Education

A transdisciplinary approach blends the perspectives of different disciplines or transfers methods from one discipline to another (Nicolescu 1999). It integrates knowledge from various disciplines through the process of inquiry and problem solving, in a way that “foregrounds the problem, not the discipline” (Quigley and Herro 2016, 412). Transdisciplinarity, therefore, helps us to think about an integrative approach to STEAM education (Quigley and Herro 2016). It requires exploring the complexity of the problems, using an integrated systems approach and addressing diverse perceptions about the problems (Hadorn et al 2008). Jang (2016) identified competencies in STEM (science, technology, engineering, mathematics) disciplines that are important to resolve complex life and professional situations. Similar to transdisciplinarity, they include engaging in active learning, critical thinking and systems thinking for complex problem solving and decision making. We observe an important connection among integrative STEAM education, transdisciplinarity and the research on design-based learning: when learners engage in participatory design practices, they develop knowledge and identity through artifacts and discourse (Kim, Tan and Bielaczyc 2015). Specifically, Nicolescu (2013) suggested that transdisciplinarity can lead the four foundation pillars of education promoted in the UNESCO report (Delors at al 1996): learning to know, learning to do, learning to live together and learning to be.

Four Pillars of Learning and Transdisciplinarity

Nicolescu's (2013) description of learning to know and learning to live together implies that the value and norms of knowledge and society are constantly negotiated within social and cultural contexts. Yakman and Lee (2012) argue for engaging students in STEAM practices to support their "ability to transfer knowledge with higher order thinking between disciplines" (p 1075). Their argument similarly emphasizes students' valuing diverse perspectives from different domains of knowledge and cultures, enhancing their capabilities in adapting to and advancing the global society. Discussing STEM competencies, Jang (2016) supports the social aspects of designing, developing and understanding relationships within and among the disciplines. He termed these competences as *social perceptiveness* (understanding others' actions and reactions to the systems) and *establishing and maintaining interpersonal relationships*. Wells's (2008) suggestion of focusing on design-based problems for STEAM education also addresses these competencies. Through the design process, students assess and employ multiple disciplines and perspectives, avoiding the practices of seeing each discipline in isolation (Wells 2008). He considers the design-based approach, in which "content is brought to bear by students on an as needed basis" (p 11), as central to transdisciplinary practices and to engaging students with the disciplinary content in a meaningful way (eg, creating a community garden).

Nicolescu (2013) also suggests that objects and knowledge are transdisciplinary in nature, and that human intelligence comes in harmony between mind, feeling and body. This indicates the notions of learning to do and learning to be in relation to the artifacts (knowledge or objects) designed, reinvented and reinterpreted by individuals, groups and society. The process of learning to do is an ability to express one's creativity (Nicolescu 2013), which makes direct relevance to the notion of learning to be, the journey of self-discovery and identity construction (Kim, Tan and Bielaczyc 2015). Researchers of STEAM education also stress learners' creative pursuits that do not set disciplinary boundaries by including art, design and humanities in their inventions (Connor, Karmokar and Whittington 2015; Jang 2016; Quigley and Herro 2016). In their framework for a holistic STEAM education, Connor, Karmokar and Whittington (2015) submit that learning to be a lifelong learner is the critical part of developing STEAM competencies. According to Dewey, students as lifelong learners would adopt habits, attitudes and intellectual skills that make them willing to explore opportunities for new experiences and reevaluate accepted beliefs (Dewey 1916, cited in Yakman and Lee 2012).

Designing Games as Transdisciplinary Approach

When designing games, students learn to determine the knowledge and skills needed for their games and to recognize game genres, rules and mechanisms for them to adopt and modify. They need to understand and create a complex set of meanings (eg, background, STEAM knowledge, aesthetics of games, rules) and to anticipate how players interact with game elements (Salen 2007). Games, as models of systems, are systemic and rule structured while dynamic when played (Gee 2008; Zimmerman 2009). Meaningful play requires a certain level of complexity, so that each game play can create unique interactions (Salen and Zimmerman 2004). We therefore concur that students learn to acquire and appreciate a rich set of skills such as system-based thinking, problem solving, art and aesthetics, writing and storytelling, iterative designing, and game logic and rules when designing games (Peppler, Warschauer and Diazgranados 2010). Students recognize the need to learn more to solve problems and make decisions for their designs, while learning to collaborate with their peers with different strengths and perspectives.

We believe that learning involves identity negotiation, or learning to be, especially when learners design their artifacts (Kim, Tan and Bielaczyc 2015). Taking on the role of game designers, learners see themselves as capable of interpreting and creating new kinds of meanings (Merchant and Carrington 2009; Zimmerman, 2009). They learn to create games while learning to be game designers. Their learning is enriched as they engage in the process of designing a context for players' participation in their games, witnessing how the new meanings arise through playing their games (Walsh 2010; Zimmerman 2009). Such an approach to game design transcends disciplinary and interdisciplinary learning and helps students develop a holistic approach to inquiry and problem solving. Connecting these ideas to the properties of transdisciplinarity, we propose that game design creates the kind of experience that mediates transdisciplinary approach to STEAM education.

Learning and Research Design

This research was conducted over six weeks with sixty Grade 8 students and two teachers (math/science and humanities) in a middle school we call Lake View School. We took a design-based research approach, focusing on reflective inquiry into an innovative learning environment in a naturalistic setting (Brown 1992; Collins, Joseph and Bielaczyc 2004). The current study was the first collaborative effort among researchers, teachers and STEAM education specialists to support students' construction of their own knowledge and skills through game design project-based learning. We decided to integrate the following learning outcomes from the Grade 8 Alberta programs of study into the game design project:

- Science: Mechanical Systems
- Social Studies: Origins of a Western Worldview: Renaissance Europe
- Math: Number Sense (Rates, Ratio, Proportions)
- English: Communication, Presentation Skills

To support students' learning and game design, the topics of mechanical systems and Renaissance Europe were divided into seven groups. Students from the two classes were assigned by the teachers into 14 game design teams. Therefore, two teams were asked to demonstrate their learning in each topic group through their game designs, presentations and group conferencing with teachers. Math and English outcomes were universal for all groups. We hoped that focusing on the subtopics would give the groups a strong foundation to learn other topics through playing one another's games.

Teachers started the process by acknowledging that students learn well by playing games but may not be interested in existing educational games. They positioned students as expert gamers who can help teachers by designing these games, thereby adopting the first step of creating a need to design games from a design thinking process—empathy (Long 2012). Teachers then facilitated "becoming-an-expert" lessons before starting on game design, in order for each team to develop their understanding of the assigned topics. To orient them into the game design, an expert board/card game designer conducted a gameplay and game design discussion session. He also suggested a role-playing card game, Dominion, as a feasible model for the students' game design. He visited the class again in few weeks to provide feedback on the students' developing game ideas. Students had multiple formal and informal playtesting opportunities to improve their game design. Their projects concluded with other Grade 8 students and teachers coming to play their games on the school's day of showcasing diverse learning approaches. Table 1 summarizes the learning activities for this game design approach.

	Rationale and Activities
Part 1: Empathy for Teachers	Coming up with ideas by empathizing with teachers "Can you develop a game that will be fun to play but also integrate curriculum?"
Part 2: Becoming an Expert	Learning topics for each group's expertise Learning from playing games with a game designer expert
Part 3: Game Design	Guiding design with game elements and structure Emphasis on learning through play, not testing knowledge
Part 4: Presentations and Game Play	Groups presenting their slice of the curriculum Playtesting for feedback Final game play with audience

Table 1: *Learning Designs*

Our conjecture for game design as their mode of learning was that students would develop transdisciplinary competences of the four pillars discussed above while gaining disciplinary knowledge of these topics. To understand this process and to create design implications, we took an ethnographic approach to observe and document their learning and design process. Throughout the six-week game design project, we captured their design activities using video and audio recording devices, which included some informal conversations that researchers had with teachers and students. We collected their evolving and final artifacts in videos and photos. Finally, we conducted formal interviews with both teachers and students to understand their thoughts about this experience.

Findings: Transdisciplinarity in Game Design Practice

Most of the groups (12) created some type of board game, whereas 2 groups chose to create role-playing card games similar to Dominion. These 2 groups had members who were regular role-playing card game players. Some of the games were more sophisticated than the others in their game structures, possible player interactions and modelling of systems. However, the value of their game design activity was apparent regardless of their levels of sophistication, considering how each group evaluated and identified the disciplinary knowledge as to what was worthy of incorporating into their games. We observed that students engaged in systems thinking through their game design, which often led them to develop deeper understanding of the disciplines, move beyond discipline-specific topic knowledge, and engage in problem-solving and decision-making processes.

Many students discussed their learning to do and learning to live together during the interview. Through game design, they had an opportunity to express their creativity and needed to find ways to collaborate with their group members. They engaged in the practice of understanding each other's skills and establishing group norms. We found that the process of learning to be has an important role in learning to know, as the students started seeing themselves as active agents in their learning and designing.

To describe students' developing STEAM competencies and transdisciplinarity in relation to the four pillars of learning, we discuss a group that created a board game called Renaissance: Rebirth (R:R). This group comprised five members (Ben, Cait, Evan, Jenna and Joe). The context of this game is the spread and impact of ideas and knowledge during the Renaissance period and Da Vinci's early ideas of hydraulics. Their game board has multiple stops that players need to visit to trade and purchase goods and resources and to build ships and houses (see Figure 1). They include two different universities, three trading posts, and two shops that sell iron and cloth.

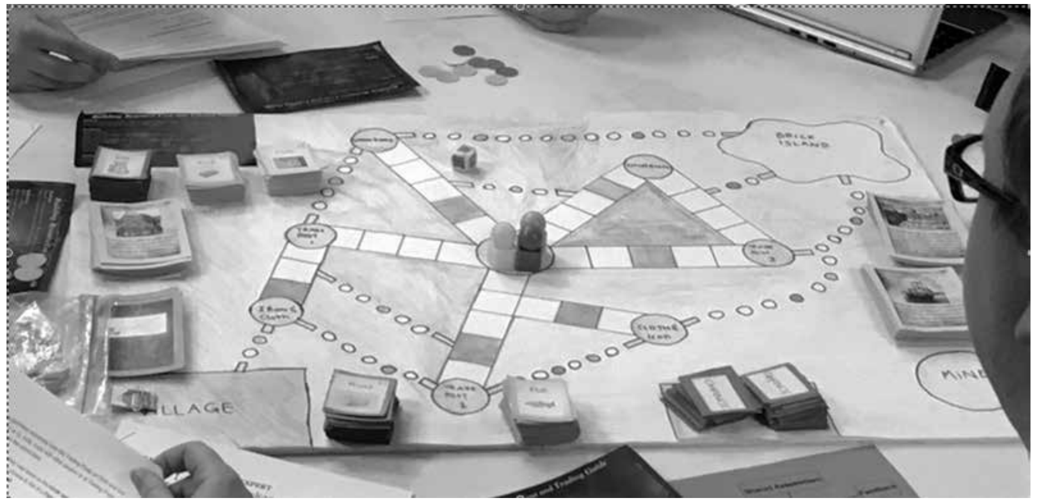

Figure 1. Game setup for Renaissance: Rebirth (R:R)

In addition to trading and purchasing resources for building houses and ships, players go fishing in certain areas and catch fish as resources to trade, providing an idea of Renaissance life. The game stresses the role of universities in spreading and applying knowledge: (1) players need to own university cards in order to build houses or ships; and (2) therefore players need to visit the universities to acquire university cards (ie, unable to trade with other resources at the trading posts). Their currencies are gold, silver and bronze tokens, which they could use to buy resources (fish, cloth, iron, wood, books, fishing equipment) at trading posts or iron/cloth shops. The game ends when the village is filled up with houses (eg, maximum of six houses for four players). The player with the most points (not the most currency) wins the game, based on the tally of the points indicated in each resource card. In the following, we first describe their learning to know and learning to live together in incorporating their STEAM understanding, and then illustrate how this group showed learning to do with learning to be in the iterative process of game design.

Learning to Develop STEAM Understanding and to Work with Others

In designing their game, the R:R group determined the knowledge and skills to incorporate into their game and adopted rules and mechanisms from the games they know. During the interview, Jenna explained about the context of including universities in the game, demonstrating how people shared ideas in Renaissance: "So we decided to have universities in our games where you have to gather certain information to do certain things." Evan elaborated on how they incorporated math (rates, ratio, proportion) by showing a series of cards (see Figure 2): "These are ratio cards … If you have four [cloth or wood resource cards] you will get one point at the end. So it is a 4:1 ratio." Cait added, "And we have trading ratios. At certain trading posts trading ratios would be different." They used ratios practically in their game rules, challenging players to learn and use this math topic through playing. Cait acknowledged that this incorporation of math concepts happened as their game rules evolved: "It kind of just came to be." Their assignments of ratio to different resources also show their process of making decisions on what would value more (eg, book = 1 vs wood = 1/4). Through this process, they learned to use knowledge creatively in their game.

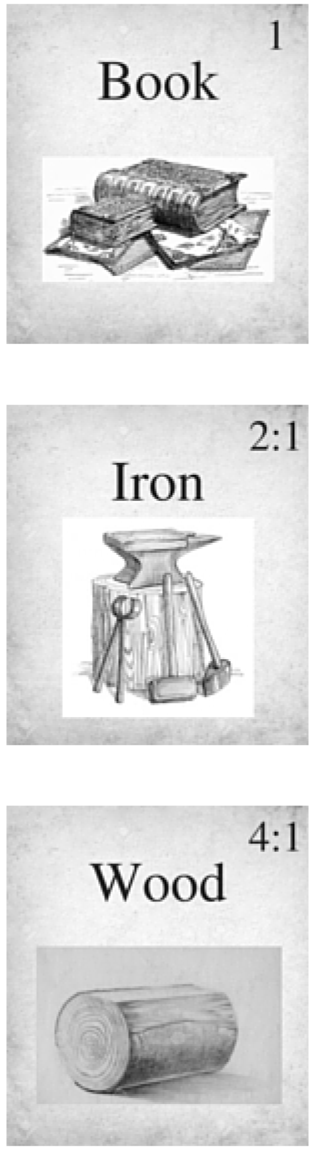

Figure 2. Resource card examples of R:R

Their work clearly demonstrates that they needed to understand, create and experiment with a complex set of meanings (ie, the Renaissance period as background, science/math knowledge, game rules and interactions). Cait, although she put it very casually, understood that creating meaningful experiences for players was more important than incorporating more learning content: "I think a lot of educational games are very focused on the learning part, so they are not as fun. If you make it fun and put additional information here and there, it is better for the players to learn." It was also apparent that learning to live together and the collaborative practice of designing and learning were appreciated by the R:R members. When asked about the important skills they needed when creating the game, Jenna and Evan mentioned "teamwork and communication." Cait also added how playtesting their game helped with communicating ideas and making decisions, "… like this is what we can do to improve the game." They learned how playtesting the game helps them express their ideas and have it understood by first-time players. The efforts made by this group exhibit the STEAM competencies, such as decision making (Jang 2016), understanding and using perspectives of others, and developing communication skills (Yakman and Lee 2012).

Learning to Create Games and to Be Game Designers

The R:R group clearly showed the process of learning to be and identity negotiation in relation to their game design practice (ie, learning to do). Joe chose *interesting* as his one-word description of game design experience and elaborated that "doing all the research for the game and understanding the ships and all the pieces" was the interesting part of his experience. Such a response may not be how students would normally discuss their school learning. He was learning to be an interested learner-cum-designer who cared about creating an informed game. We believe that this indicates a good start for developing as a lifelong learner. R:R group members also showed their position as well-informed game designers. They valued the evolving designs of their game and the iterative process of playtesting as they articulated their design changes:

> Cait: Originally our chance cards had more complicated situations. For example, they would lose more resources. We realized that that would definitely be frustrating for players, so we took those cards out.
>
> Jenna: We also changed our die. We originally had a regular 1-6 die. Matt [game design expert] suggested to have a 4-6 die, so players wouldn't get frustrated [by rolling lower numbers].
>
> Evan: And they didn't have to land on the chance [to draw a chance card]. All you have to do is to cross over the red square and pick it up as you go … It was one of our changes when we were playtesting.
>
> Cait: And when we had a 1-6 die, it was possible that players move only one square, because they could get 1 and it could make them frustrated.

As designers, they believed that there is always room to improve their game, even though R:R received positive feedback from the playtesting. For example, they articulated how they would like to make their game shorter because its play time was longer than expected:

> We would change it in a way that fewer resources are required to build a house. Now people have to move a lot to go to certain spots to collect the resources. This takes two or three turns for each player. It decreased the competition in the game because people had to do certain things to get a ship and start building houses. We hoped people had more interaction and trades among themselves.

They were learning to be good learners and designers. They also appreciated the opportunity to work with peers that they do not normally work with, who stimulated different ideas, and wished to have more time to further improve upon their game design.

The groups who were not able to develop a sense of group identity as codesigners, on the other hand, showed a stark contrast to groups like R:R. They found the game design activity repetitive and uninteresting. These groups tended to have less complex games that often depended on knowledge-based progress on a game board (eg, player answering a question on an action card to proceed). Students in one group thought they were given too much time to improve and finish the game to their satisfaction. After four people said something similar, one of the members reiterated, "Like what they all are saying, it was super repetitive and you couldn't work with your friends, who you normally work with. So it was harder." Another member added, when asked about how they might improve on the game, "I wouldn't do anything, because it is all already very good … [It is] perfect. Maybe we like to make a hard copy of our game and sell to Superstore and Chapters."

Unfortunately, these groups did not appreciate playtesting and multiple design iterations for further improvements as an indispensable part of the design process. The nature of their design (knowledge focused) did not challenge them to engage in system-based thinking and learning. They articulated their accomplishment of how their game evolved from a "bad game" to a playable fun game, but their comments do not indicate constructing identities as designers, experts or learners who seek new experiences. Their description of the project could indicate that they saw it as just more school work with the goal of learning certain discipline-specific knowledge: "It was kind of useless that we learned all the information and then we were teaching other people with our game and presentation."

We could still see them engaged in problem solving and decision making as they tried to improve their game, which, as they mentioned, was initially a "trivia" game and "not fun." Despite some final games not being as complex as R:R, we believe that their involvement in the game design practices helped them develop some level of transdisciplinary STEAM competencies. The students developed a good understanding of simple machines and Europeans' exploration of the world during the Renaissance with the goal of spreading their religion and expanding their trades; the students also tried to create the interconnections among disciplines and incorporate them in their game context.

Conclusion

The findings in this paper demonstrate that game design practices facilitate a transdisciplinary approach to STEAM education. Learners bring in their own ideas and experience to engage in academic practices with their peers, teachers and mentors. They invent a set of rules adopted from their disciplinary understanding, and they design dynamic systems for players to create new patterns and interactions within their games. Our findings also indicate that we need to support their design of complex, system-based and strategy-focused games much earlier on in order for them to move away from trivia games, engage in much more meaningful experiences and develop their transdisciplinarity.

This study invites teachers to use the lens of transdisciplinarity and the four pillars of learning in the design of an integrative STEAM education. Transdisciplinary design practices encourage learners to appreciate perspectives from different domains of knowledge to create solutions for real-world problems, and to use various ways to communicate their viewpoints. Put differently, these practices could support students' learning to know and learning to live together. Our findings suggest that teachers could use game design practices to create more inclusive learning environments that engage students with different skills and interests. Game design projects open the space for students to pursue their disciplinary and cross-disciplinary interests, and to express their creativity by contributing to collaborative design practices. This type of design practice specifically addresses learning to be and learning to do as two pillars of learning.

In this paper, we provided both theoretical and practical views on how learners' developing transdisciplinary STEAM competences may contribute to their individual and collective learning of multiple disciplines. We witnessed how learners' designing games for both their own and others' learning challenged them to transform their ideas into creative, communicative and coherent expressions of a playable game. We suggest a collaboration among teachers in different disciplines for an intentional design of integrative curricula (Wells 2008), with which teachers would model the transdisciplinary approach to their own design practices. We hope that this study contributes to the practice of using game design as a transdisciplinary approach to help learners think creatively, flexibly and systematically for any discipline.

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