ACHIEVING SCIENTIFIC LITERACY: AN INTEGRATED CURRICULUM APPROACH TO ENHANCING SCIENTIFIC LITERACY FOR STUDENTS

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Abstract

This paper describes the development and implementation of an innovative high school science course to improve students' scientific literacy. The goal was to create a rigorous and thought-provoking course to engage students in contextually relevant learning focused on the core concept of scientific literacy. The challenge was to teach the prescribed Programs of Study for Science 10, Mathematics 10 Common, and Chemistry 20 in the time normally needed to teach only two of those courses so students would make connections and apply knowledge across the disciplines. This has been achieved through interdisciplinary projects throughout the year. This successful project was named Scimatics. I encourage others to create similarly meaningful courses for their own students using their and their students' passions and expertise to guide them.

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Introduction

Prior to taking my masters, I thought of high school curriculum in terms of distinct subjects (or disciplines) compartmentalized and laid out by a group of people who had been selected by the provincial government to determine which concepts in each of these disciplines was important. I thought of teaching as an occupation which required patience, humility and intelligence; all qualities which I thought necessary to work with students who were likely not interested in what they were learning. My job was pretty easy. I taught what I was supposed to, took care of the students in my classroom, coached the sport I love, and was a well-liked member of our staff. My students liked me because I was fun, I was patient with them, and I cared about them. My colleagues liked me because I was fun, humble, and had a strong sense of deference for anyone older than myself. My administration liked me because I was intelligent enough to learn anything they asked me to and willing to teach anything they asked me to as well as I possibly could. I was a good teacher and I really liked going to work every day.

After about a decade of working at a great school with supportive colleagues and wonderful students, I was finally in the place I wanted to be; I was teaching the highest level of chemistry to the smartest groups of students in the school. It was what I had been working toward for my entire career. After two years of being where I wanted, I realized something that scared me . . . I was bored. I struggled with this realization for several months and considered changing locations, but I had a strong attachment to my school. It is the oldest high school in my city and I loved its history. It is located in the community in which I live, that I grew up in, and that my children would eventually attend. I did not want to leave what had essentially become my home. Fortuitously, at teacher's convention that year, I came across the booth for the University of Lethbridge where they were providing information about a new Masters of Education in Curriculum and Assessment.

A master's degree in curriculum and assessment was far more appealing to me than a master's degree in educational leadership. I was passionate about teaching well, concerned with finding ways to improve students' learning experiences in meaningful ways, and interested in developing a deeper understanding of pedagogy and teacher leadership. I decided to embark on a new educational journey and it was exactly what I needed to quell my boredom and to introduce me to the fundamental concepts and constructs of education. My personal journey as a master's student has taken me far beyond my original expectations of what being a better teacher would require. I have come to understand that genuine learning occurs when it is personal for the learner, when there is curiosity about a concept or construct. Finding ways to develop learning experiences that afford students opportunities to explore their own interests, while learning about a prescribed set of learning outcomes has awakened a new hunger for creativity and innovation in my pedagogy. I have become inspired to teach and to learn with my students. I have developed the confidence to share what I have learned and created with my colleagues. I have acquired the leadership skills to inspire them to be more creative and innovative in their classrooms. I have become a courageous teacher.

Why Courage Matters

In the competitive world of high school math and science courses including Chemistry 30, which I teach that culminates in high stakes standardized tests (in Alberta, these are developed by the government and called Diploma Examinations), one thing seemingly counts above all else. . . test scores. Students' results on these tests provide ready-made data which is easily scrutinized by stakeholders including the public, school district executives, school boards, and school administrators. The ability to compare results between a school and the rest of the province, a school with other schools, and even an individual teacher's class with other teacher's classes requires almost no work on the part of the inquiring party. And often, in my experience, the results achieved by students on these exams are considered a direct reflection of a teacher's quality in the classroom. I have heard several times in the course of my career that high quality teachers get good results on diploma exams. I have also been told directly by some administrators that as long as I continue to get good results, I could continue to teach chemistry. So I did what I think most teachers in my situation do; everything I could to get those good results.

Before I started my masters, I think the most significant thing I did that had a positive impact on "my results" was to make sure I taught and assessed every single specific outcome in the Program of Studies. This allowed me to know what level of understanding my students had with respect to virtually everything they could possibly be tested on. It also allowed me to become an expert in the content of the courses I taught, especially Chemistry 20 and 30, which are the highest level high school chemistry courses in Alberta. As I gained a deeper understanding of outcomes-based assessment, I also learned about the power of formative assessment as a form of learning. I began to value formative assessment more than summative assessment because I felt it gave me the freedom to help students learn without the fear or weight of grades. I could help them overcome their misunderstandings or improve their understanding before I reported on it. It was truly liberating. I was convinced that formative assessment was at the very least, a harmless learning activity, and at most, a key to real understanding of concepts.

Sharing my knowledge with my colleagues about formative assessment was my first experience with courage. The concept of asking students to do work that did not count for grades was met with a lot of resistance. How would the students be motivated to do anything that did not count for grades? Where would teachers get the time? Why would we waste the precious time we had on learning what we had to re-teach instead of just removing the students that did not belong in the class? These were very real concerns, for me as well.

I was fortunate to be part of a small group of teachers that saw the potential and we bounced some ideas around and eventually gained enough confidence to try it. It seems almost silly now to be writing about how daunting it was to have students write a quiz that I was never going to mark, but in that moment I was terrified that I was wasting precious time for potentially nothing at all. I was very happy to discover for myself that formative assessment did work. I saw that my students were actually learning better with formative assessment tasks and that subsequently, they were performing better on summative assessments. Sharing this information was not difficult—what was difficult, what required courage, was sharing *why* it worked.

It takes courage to articulate ideas to colleagues that require them to change. In my high school teaching experience, most teachers are content with how they deliver their lessons and with the assignments and tests they give year after year. It usually takes something like a major change in the Program of Studies to give them a reason to modify or alter what they are doing in the classroom; and often externally imposed changes are met with resistance and pessimism. Why change something that works and that gets good results? Personally, I have been dismissive of externally imposed initiatives which I thought inapplicable to my context or, in my opinion, which focused on issues that did not pertain to my situation, and have had conversations with colleagues who felt the same. The reason for this, I believe, is that high school science and math teachers who teach the highest level courses are often solitary experts in their disciplines. This is a prestigious and lonely place to be. One must know a great deal about mathematics, chemistry, or physics to teach courses like Chemistry 20 and 30; and generally, there are few teachers who deliver these courses in the same building; and in rural settings, one teacher is often responsible for all of them. Much of the time we find to collaborate is used to exchange or discuss assignments, clarify understanding of content, or to analyze new resources.

We have little experience with collaboration for the sake of pedagogical improvement. Courses like Chemistry 20 and 30, Physics 20 and 30 and Mathematics 30-1 or 31 are commonly experienced by students who are university bound with hopes of studying medicine or engineering. These are usually good students who have a solid work ethic to begin with; therefore, little modification of instructional design is required to reach these top students from year to year.

Given that I had a prestigious course load, was teaching the most academic students, was getting good results, and had good job security due to the level of expertise required to teach the courses I was teaching, why did I ever consider changing anything about the way I taught? The initial steps I took with formative assessment were just the beginning of my change. When I started to see that students were learning concepts more effectively, not just remembering the “stuff” I had told them, I knew I was heading in a direction that could positively impact student learning. The immediate results I observed in my classroom were far more rewarding than the diploma results that I saw several weeks after my students had written the exam. Having an immediate positive effect on learning in the moment for the students sitting in my classroom was exciting for them as well as me. I needed to change the way I thought about planning to make learning meaningful for all of my students as they were learning, and not wait to make changes until the following semester (or year) for students that may not have the same difficulties and strengths.

I started to recognize that although I had many strengths, I had deficiencies in pedagogy. I needed to change how I approached planning lessons, units, and even entire courses. This required research, reflection, collaboration, and, most of all, courage. For me, the courage to allow inspiration and creativity to guide planning, and to collaborate meaningfully with colleagues was made possible through a combination of some key and timely factors: I had a passion for assessment; the school I taught at was involved in the Moving Forward with High School Redesign initiative; the school was about to start offering two university courses as part of the province's Dual Credit Strategy; and I began my Masters of Education studies in Curriculum and Assessment.

The Need for Change

My desire to take a more innovative approach to teaching was triggered by a few external influences. Alberta Education's initiative, Moving Forward with High School Redesign, is a program based on a philosophy which focuses on redesigning high school so it is more student-centered. The goals are to increase student engagement, increase student achievement, and provide high quality teaching (Alberta Education, 2019). This program enabled high schools to drop the Carnegie unit (25 instructional hours per credit earned) and be creative with the time table in order to provide a more flexible learning environment for students. This required teachers to reflect on their pedagogy and find ways to increase engagement in their classrooms, and it was necessary to participate in more personalized professional development which was tailored toward individual teacher needs to find ways to provide rigorous and relevant learning opportunities for students. This allowed me the time and learning I needed to teach three courses in the time I would normally teach only two.

Another important was the development of a partnership with the University of Lethbridge to offer two university classes to be taught at the Lethbridge Collegiate Institute by university professors. Alberta Education's Dual Credit Strategy is a program that offers high school students the opportunity to take post-secondary courses while in their high school environment with the goal to assist students in the transition from high school to post-secondary (Alberta Education, 2017). By successfully completing one of these courses, students earn five Alberta high school credits and three University of Lethbridge credits. The university credits are transferable to any post secondary institution that accepts the courses. These courses are additional to the regular classes that students take in high school and therefore, there was a need to create space in students' timetables. I volunteered to create a class in which students would complete three high school courses in the time they would normally complete two to create this open space for them. Had it not been for the liberty from the Carnegie unit, the partnership with the University, and an administration that supported creative and innovative teachers, this would not have been possible.

I was very fortunate that I was starting to work on my Master's Degree at this time and was able to focus my studies on the creation of this course. I decided to focus my second summer project on the development of an integrated curriculum for the course and to determine whether the integration of math and science would improve student learning.

I was also, and still am, passionate about the efficacy of assessment. I believed the key to learning was purposeful assessment, and that developing meaningful assessment tools would be the most important aspect of the course for the students. I was also able to relate my professional development to the creation of Scimatics by developing assessment tools that would assess learning in both math and science simultaneously. I explored the potential for curriculum integration within the Alberta Programs of Study for Math 10 Common, Science 10, and Chemistry 20; resulting in the successful creation of an innovative course called Scimatics. The course is designed to focus initially on students' interests, and it is through their own exploration of these interests that they make connections to the existing curriculum. The course involves a few significant projects, which span several weeks, or even months, of class time. Normally, these classes are taught as three distinct courses and no attempt is made to link ideas from each of the classes. Scimatics, however, is taught as one course and students are required to make connections between traditional disciplines to understand the relevance of the concepts they are learning in class to current technological and environmental issues, and to communicate their understanding of the connections confidently.

This was an overwhelming undertaking. I thought, at first, that I would simply look at the curriculum, figure out some redundancies to save some time, and combine some existing assessments into more meaningful ones. In looking back, I did end up doing these things, but I was only able to do so after I had redefined the focus for the course. The first step towards integration was to realize that the core learning goal had to be *increasing the level of scientific literacy that students achieve*. Thus, I embarked on my journey by exploring the need for disciplinary expertise.

The necessity of disciplinary expertise

One of the things I most love about teaching is the emergence of the unintended and unexpected outcomes of assessment and instruction as they provide rich opportunities for learning, for me as much as for my students. The more I teach, the more I realize that these “situations” do not detract from the required curriculum, but serve as true encounters with the concepts and content that I teach. This is wonderful and exciting place to be in a high school science classroom for teachers who are experts in their discipline, but it can be terrifying for those who are not experts, or who are teaching something for the first (and maybe only) time.

In science, teachers are supposed to encourage students to be curious. The first goal of the Alberta High School Science Program of Studies is “Science education will: encourage students at all grade levels to develop a critical sense of wonder and curiosity about scientific and technological endeavours” (2005, p. 1). For high school teachers who are not fluent in the discipline they have been assigned to teach, encouraging such student curiosity is difficult. Conveniently (or thankfully), the *Teacher Resource Manuals* provided by textbook publishers invariably provide activities to manufacture curiosity to lead students to the “discovery” of prescribed knowledge. More often than not, students' inquiries that are beyond the scope of this manufactured curiosity are dismissed or ignored at the expense of “getting through the curriculum”; when in reality, it is likely that the teacher cannot address them with confidence. (I certainly could not when I was in the early years of my teaching career.) We science teachers must realize where these inquiries come from. We want students to ask questions, and we need to be comfortable with them asking questions that we are not necessarily prepared for. For the most part, the questions they ask in our classrooms stem from experiences they have in our classrooms; from instruction we provide, from activities we engineer, from assessment we use (and hopefully develop), and from discussions we have. We must be able to create learning experiences for our students that allow them to ask genuine questions, and we have to be able to address them with confidence. We must also accept—even promote the idea—that teachers do not always have to be able to *answer* every question, just have the capacity to *address* them.

Each one of these genuine questions provides me with an opportunity to participate in an authentic learning experience with my students within the discipline in which I teach. If I was not at least somewhat of an expert in chemistry, I would not have the confidence to address these situations productively. I would not have the ability to modify my instruction to enhance all students' learning, and I would not have the courage to try new instructional and assessment methods to give my students better learning opportunities.

I would argue that the vast majority of questions students ask me that are seemingly unrelated to the curriculum, are actually directly related to the curriculum in one way or another. Most likely, the student is asking a question sparked by some thought arising from accumulated knowledge and personal experience. The student is seeing a connection between what they are experiencing in one class to something else: it could be from another class, from some personal interest, something their family members have done or talked about, or something they read about or watched online, or something they learned about while playing a video game. If the students can see these connections and teachers can acknowledge the relevant connections between curriculum and personal curiosity, then we encourage genuine learning rather than stifle it by dismissing such questions as a "waste of time". Disciplinary expertise is required to plan and deliver this type of course because we must be able to see relevant connections between the disciplines and we must be confident to address all questions that we are asked in a non-dismissive way.

I began the exploration of disciplinary expertise as a requirement for successful curriculum integration at the beginning of my studies as a master's student and I continue that exploration today. Over the last several years I have come to the conclusion that disciplinary experts are necessary to teach integrated curriculum courses. As an expert, one has the confidence to be creative and innovative with the content about which they are passionate, as well as the contexts to which that content may apply. In their article "Disciplining the Mind" Mansilla and Gardner (2008) state "Subject matter learning may temporarily increase students' information base, but it leaves them unprepared to shed light in issues that are even slightly novel. A different kind of instruction is in order, one that seeks to discipline the mind" (2008, p. 16). They go on to describe four key capacities they argue pre-collegiate education should include: Understanding the Purpose of Disciplinary Expertise, Understanding an Essential Knowledge Base, Understanding Inquiry Methods, and Understanding Forms of Communication (Mansilla and Gardner, 2008). The foundational principles of these four capacities transcend all disciplines and, as teachers, we should strive to awaken these capacities within our students through relevant instructional practices, providing them with assessment tools that enable learning rather than just provide evidence of acquired knowledge.

The rationale for employing teachers with disciplinary expertise in the high school classroom is that "disciplines inform the contexts in which students live" (Mansilla and Gardner, 2008, p. 17), disciplinary thinking provides ways of knowing and thinking about contexts. Students can explore the same context or issue from multiple perspectives within one discipline, such as science, and we can also consider an issue from the lenses of several disciplines. To make judgements or come to conclusions about social and environmental issues, students must have the ability to think critically about these issues from different perspectives. Experts, including teachers, provide students with the necessary tools to achieve higher level critical thinking skills within the expert's area of expertise.

Take for example, the issue of food. What should people eat? Why should, or shouldn't, we eat this or that? This question can be looked at from myriad disciplinary perspectives: scientific, cultural, social, geographical, aesthetic, and even mathematical. Each of these disciplines has a particular way of considering the issue and relevant data related to it. The "essential knowledge base... equips [us] with a conceptual blueprint for approaching comparable novel situations" (Mansilla and Gardner, 2008, p. 17). In class, students could look at the caloric value of food, or food as a source of essential nutrients, as science generally does. Or they could consider food in terms of what people of a particular culture identify as good food, or what is acceptable to eat among peers and families when contemplating food choices. However, it is just as important to realize that gaining disciplinary knowledge comes from "a careful process of inquiry and vetting claims" (p. 18). How does the public get all this information about food? And why ought we to put more value on one perspective than another? Is counting calories more important than cultural tolerance? Inquiry is the process through which students obtain permanent knowledge. Considering all the relevant perspectives related to food choice leads to a deeper understanding about why people eat what we do and why we may want or need to make changes.

Communicating constructed knowledge to an appropriate audience is the fourth capacity discussed by Mansilla and Gardner and also the final step in demonstrating obtained knowledge in a classroom setting. It is perhaps at this point that we teachers ought to be spending most of our time growing. What we must consider is that the traditional paper and pencil tests we are currently using may not allow students to communicate truly relevant information. Tests which are comprised primarily of selected response questions must be carefully scrutinized to ensure that they do not function simply to indicate how much subject matter a student has managed to remember at the point in time that they write a multiple choice or other selected response test. Open ended response questions may be able to provide the necessary context for students to express their knowledge to a greater extent, but it is important to scrutinize these types of questions as well in order to ensure that more than knowledge recall is being assessed. It was my personal experience that the paper and pencil tests I adopted from those who preceded me simply did not afford students with opportunities to communicate their own constructed knowledge in a contextually appropriate manner. I came to this conclusion through a thorough analysis of the tests I was using. I mapped them to the Program of Studies to determine whether the outcomes were appropriately represented and found that not only was there significant over and under-representation of certain outcomes, but the level of questioning was not adequate to engage students in higher levels of cognition. Considering Anderson and Krathwohl's Taxonomy (a 2001 adaptation of Bloom's Taxonomy from 1956), as described by Leslie Wilson in her 2016 article *Anderson and Krathwohl–Bloom's Taxonomy Revised*, there were many selected response questions that required students to remember, understand and apply learned factual and conceptual knowledge and very few constructed response questions that required students to analyze a given context and apply procedural knowledge. There were virtually no questions that caused them to evaluate contextually relevant criteria or create any sort of meaningful representation of their newly acquired knowledge. For me, this was a lesson in the importance of analyzing our own assessment practices and cultivating them to respect the nature of the knowledge they intend to assess. The journey required to design relevant assessments coincided with a deep exploration of curriculum and the development of a construct through which to anchor an appropriate pedagogical approach to instruction and assessment. Essentially, I realized that what I needed to do was define what I wanted my students to achieve: a higher level of scientific literacy.

Review of the Literature

My research focused primarily on developing the construct of scientific literacy to determine how to increase the level of scientific literacy achieved by students in high school. Rather than finding methods to do this, I found an emergence of concern about the failings of the education system in producing scientifically literate citizens and that, despite the awareness of this issue, educational reforms intended to address it did not do so adequately.

The literature revealed that students do not leave high school with a good sense of scientific literacy (Bybee, 1997; DeBoer, 2000; Deming, O'Donnell, & Malone, 2012; Hurd, 1998; Lederman, 1992; Lederman, Lederman, & Antink, 2013; Soobard & Rannikmae, 2011). They do know facts about science, about mathematics and about technology, but they fail to see how all these facts could be considered simultaneously to provide solutions to the practical problems that human beings encounter or to expand human capabilities (Lemke, 1998). I believe this is a result of the learning experiences students have in high school, where knowledge is compartmentalized into subjects and which are taught and assessed independently.

During the first decade of my fourteen years experience as a high school science teacher, I taught science based on the distribution of specific outcomes in the *Program of Studies*. The learning outcomes are classified in four broad categories:

- *Knowledge outcomes*—include the bits of accumulated information and data which are accepted as important and fundamental related to particular concepts within a science discipline
- *Skills outcomes*—include the procedures required to carry out activities related to science concepts
- *Attitudes outcomes*—include the traits and qualities of a scientist
- *Science, Technology and Society (STS) outcomes*—include the relationships of science with the world and its relevance within it

Figure 1, which I created by simply counting the number of each type of specific outcome in the Science 10 Program of Studies, displays the relative number of specific outcomes in the document.

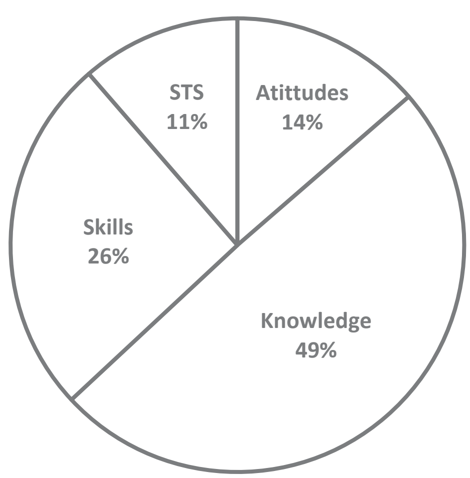

Figure 1. Distribution of Specific Outcomes in the Alberta Science 10 Program of Studies

I equated value of outcomes to number of outcomes. This puts greater value on knowledge outcomes and lesser value put on skills, then attitudes, and the least value on the STS. This influenced the way I planned in science. I thought it important to get through the content knowledge first, then do experiments if there was time… and if there was time after that, I might discuss some issues that could be related to the content knowledge.

Planning generally followed this this sequence: first, cover the content knowledge, then let the students do some labs to gain some skills and appreciation of scientific attitudes, and finally, discuss current relevance if there was time. After several lessons during which I told my students things they needed to know, I would test them to see if they knew it all, re-teach most of it, test them again to see if they knew more and repeat the process until I ran out of time. I was afraid to let them do a lab if they did not understand the concept first, and I hardly ever had time to discuss current events in science or even address their authentic questions related to science. I did a lot of talking and the students did a lot of listening. It was just as I had learned about science and it was, for the most part, boring.

On reflecting why my personal experience with teaching the sciences has primarily focused on content, I realize the main reason is that the specific outcomes of science curriculum are written predominantly from what Deming et al. (2012) describe as "the philosophical model of scientific literacy which describes the content knowledge and conceptual understanding that is desirable for future scientists" (p. 10). The focus on content knowledge is relatively simple to explain. We teachers know that our students will be tested on content, therefore we learn it and teach it. Curriculum updates are also focused on updating content knowledge within the traditional subject disciplines. These updates require teachers to update their plans to provide adequate instruction with a focus on content. Since the vast majority of curriculum documents are dedicated to specific outcomes which focus on subject matter, and these outcomes are those which are assessed on standardized tests, and the results of these exams are often used to evaluate teachers, it is on these outcomes that teachers focus in the classroom. I would argue that this does not lead to an increased level of scientific literacy in the general population for the reason that the number of students that go on to post-secondary and continue to use this knowledge to become scientists is very low, thus the subject matter that science teachers share with their students is largely forgotten by them when they are no longer required to use it. When it comes to conceptual understanding, which requires scientific thinking skills such as scientific inquiry, problem solving, and testing and revising hypotheses, we teachers tend to provide very few opportunities for our students to develop them. Over the years of my career, I have realized that subject matter is not memorable unless it is acquired in such a way that makes it permanent; and scientific thinking skills are necessary to make meaning of the content of science courses. Although this statement may seem perfectly straight forward, this determination was transformational for me.

If I was going to integrate curriculum from several classes to provide students with an opportunity to increase their level of scientific literacy, I could not simply look for redundancies and put curriculum together in a shared time and space; I was going to have to teach it differently. I had to shift my focus away from ensuring I was covering content knowledge or sharing subject matter, and toward providing students with opportunities to make relevant connections between the curriculum and the world around them. This would require more pedagogical changes than content rearrangement; and achieving this mind shift was the key to successfully delivery a course like Scimatics. The challenge was in the reconciliation of the discrepancy of disciplinary competence and pedagogical competence.

I would argue that to come to this necessary mind shift, the teacher must realize the implications of imparting their level of disciplinary expertise with a given instructional method. Zeidler and Lederman (1989) posited that “the language teachers use to communicate science content may provide the context… in which students come to formulate a world view of science” (p. 1). In his article “Students’ and Teachers’ Conceptions of the Nature of Science: A Review of the Research”, Lederman (1992) summarizes his findings concisely:

> In general, when teachers used “ordinary language” without qualification (e.g., discussing the structure of an atom without stressing that it is a model), students tended to adopt a realist conception of science. This conception views scientific knowledge as true, real, existing independently of personal experience, and where some scientific objects (e.g., atoms, light, ions) have the same ontological status as ordinary objects (e.g., chair, table). Alternatively, when teachers were careful to use precise language with appropriate qualifications, students tended to adopt an instrumentalist conception. The instrumentalist view emphasizes the practical utility of scientific explanations, the role of human imagination and creativity in the development of scientific knowledge, the tentative nature of science, and the utility of arbitrary constructs and models. (p.348)

In my experience, precise language comes with high level understanding, thus it follows that higher levels of disciplinary expertise lead to more accurate use of precise language. If, as Lederman argues, this is requisite for students to develop what he calls an *instrumentalist conception* of science, then it is important that teachers are able to balance their precise language with engaging, appropriate, and meaningful delivery. To put it plainly, rather than talking over the students’ heads’, the teacher must generate a sense of curiosity and inquisitiveness about the precise language they are using. This, however, is not enough. Curiosity stems from a sense of wonder about something seemingly new or unknown (such as the qualification of a precise term). In my experience, if a student is truly curious about something, it is either because they are trying to make sense of it in relation to things they already know and understand, or they have heard something related to it in another context. Since students generally reveal their curiosity in the form of a question, the way in which teachers interpret and answer these questions is profoundly important. This is where pedagogical knowledge, experience, and even humility become significant.

The content taught in schools is not absolute and how teachers currently understand it is not necessarily exact. It is because of genuine curiosity that science has become a way of understanding the world in which we live; an understanding that develops and even changes as a result of human imagination, innovation, and creativity. The progression in our understanding of Earth's place in the universe is but one example of myriad concepts that taken for granted as "knowledge". Understanding of astronomy has changed almost completely since the beginnings of science because scientists observe, hypothesize, test, retest, and ultimately challenge knowledge simply because they are curious, and new technology allows people to see further. Science, by nature is tentative, due to the curiosity of humans, and our capacity to create new, more appropriate, and precise scientific knowledge (McComas, 2004). If teachers are to inspire students to increase their own scientific literacy and possibly continue the expansion of human understanding, then their curiosity cannot be stifled by simply teaching the content knowledge outlined in the Program of Studies and denying its tentativeness. Teachers need to let students explore the *why* when it comes to constructs and models changing over time and encourage them to follow their own curiosities.

In a more recent article, “Nature of Science and Scientific Inquiry as Contexts for the Learning of Science and Achievement of Scientific Literacy”, Lederman, Lederman and Antink (2013) argue:

> From the perspective of currently advocated pedagogy (i.e., constructivist approaches), an understanding of NOS [Nature of Science] and scientific inquiry underlies the essence of the Teaching and Assessment Standards specified by the National Science Education Standards. It is not at all difficult to argue that a teacher who lacks adequate conceptions of NOS and scientific inquiry, or a functional understanding of how to teach these valued aspects of science cannot orchestrate the types of instructional activities and atmosphere, or assess students' progress, as specified in the various reform efforts in science education. Indeed, a functional understanding of NOS and scientific inquiry by teachers is clearly prerequisite to any hopes of achieving the vision of science teaching and learning specified in the various reform efforts. (p. 139)

The reform efforts to which they refer are those which have long permeated science education, curriculum reform to increase scientific literacy.

> Despite numerous attempts, including the major curricular reform efforts of the 1960s, to improve students' views of the scientific endeavor, students have consistently been shown to possess inadequate understandings of several aspects of NOS and scientific inquiry (e.g., Aikenhead, 1973; Bady, 1979; Broadhurst, 1970; Lederman & O'Malley, 1990; Mackay, 1971; Mead & Metraux, 1957; Rubba & Andersen, 1978; Tamir & Zohar, 1991; Wilson, 1954). (p. 139)

In developing my own understanding about integrating curriculum and how it relates to scientific literacy and pedagogy, I came across Marcella L. Kysilka's 1998 article entitled “Understanding integrated curriculum”. She states:

> For the curriculum to become more meaningful to learners, they need to see a connection between what they are learning in school and what information, skills and knowledge they use in real life situations. Since in real life content is not segregated into its respective pieces, 'integrationists' contend that the way in which students should learn content in school is not in segregated, unrelated bits and pieces, but as a whole body of related information which is then utilized appropriately in daily life activities. Thus integrationists are examining ways to bring meaning to the curriculum by rethinking how the curriculum can be planned, organized or reconstructed to provide these opportunities for meaningful learning. (p. 203)

This statement exactly reflects what I was trying to achieve with the creation of the Scimatics course. I wondered why I had not done anything like this yet. If the research is saying that it is possible and that it should be done, why are schools not doing more of it? Kysilka posits there are four main reasons why teachers are reluctant to change the way they deliver curriculum: (a) standardized tests, (b) time, (c) parents, and (d) teachers' own knowledge base (1998). I found it very interesting that these were essentially the same *excuses* I had heard or thought of myself, not just for integrating curriculum, but for just about any educational change.

I have become far more reflective and contemplative about what I am doing in the classroom, with my colleagues and with other stakeholders. At this point, I would say that the best possible way to address the issue of teacher efficacy in these areas is by minimizing the gap between disciplinary knowledge and effective teaching methods within the discipline through personalized professional development. Teachers who wish to teach a course like Scimatics must embark on a professional learning journey through which they not only familiarize themselves with current pedagogical practice, but actually immerse themselves in the struggle to understand the theory of pedagogical change. They must also attain a high level of expertise within their chosen discipline. A deep understanding of a discipline allows teachers to recognize good questions when they arise, as well as the capacity to navigate the exploration of these good questions. As I began my exploration of science related pedagogy, I found myself with more questions than answers.

The Questions

During the initial stages of development, it seemed that all I had were questions. I needed to define the purpose of the course and determine whether integrating Science 10, Math 10 C, and Chemistry 20, and then assessing student learning would enhance, enrich, or augment student learning in these areas. David Slomp's "Integrated Design and Appraisal Framework for Ethical Writing Assessment" (2016) provided a straightforward and helpful approach to addressing the concerns that arise when developing curriculum and relevant assessments:

> This heuristic provides a solid framework for highlighting the major concerns assessment developers need to pay attention to when designing assessments. The IDAF model I am
> advancing extends Huot's framework by expanding the range of questions that must be considered, and by providing clear direction on how to translate the answers to these questions into procedures for assessment design. (p.4)

The initial questions I had reflect the depth and breadth of issues to be considered when embarking on the development of an interdisciplinary curriculum. Below are the original questions from the journal I kept during the development process:

- What are the information needs of students, teachers, or administrators that you need to fill?
  - Are students making inter-curricular connections?
  - Am I applying appropriate and thoughtful methods of integration?
  - Am I respecting the math teachers' requests to keep math "pure" while at the same time showing these teachers the potential of integrating complimentary content in hopes of convincing them that this approach is beneficial?
  - Does administration see the value in this pedagogical approach to learning enough to allow it to continue in the future?
- What do I want to know?
  - About or from students?
    - Do they feel appropriately challenged?
    - Are they seeing relevant connections between the traditionally separate courses?
    - What do they like about this learning experience?
    - What do they not like about it?
  - About or from teachers?
    - Do math teachers have confidence in this approach?
    - Do I have enough assessment experience right now to create meaningful, relevant, and comprehensive assessments?
    - What questions and apprehensions do teachers have about integration?
  - About or from administrators?

        - Are they hearing positive or negative feedback from students, parents, teachers and other relevant stakeholders?
        - Do they see the pedagogical value in integration?
- What inferences about student learning or program functioning do I hope to be able to make from my assessment data?
    - I hope to see that integrating math and science curriculum is an effective way to challenge and inspire academically talented students.
    - I also hope to see that integrating curriculum can be beneficial to all students regardless of their ability.
    - Finally, I hope to see that the learning experiences which are collaboratively generated between teacher and students are more powerful and enduring than if meaningful connections between content areas are left to students to find on their own.
- How will I use this assessment data?
    - To promote the use of integrated approach to learning for high school students.
- What decisions or actions will I take based on this data?
    - I will decide to continue to improve my instructional methods in the area of integrated curriculum.
    - I will convince my colleagues and administrators that this is a worthwhile and valuable learning experience for students, not simply a way to open up space in their timetable to take dual credit courses (or AP courses) offered at our school.
- Who are the stakeholders that will be impacted by this assessment procedure?
    - Students, parents, teachers, and administrators.
- What voice will they have in the design, implementation, and use of this assessment?
    - Math teachers will contribute to ensuring that content in their area is covered appropriately and to acceptable depth for academically talented students.
    - Science and math teachers will assist in collaboratively creating appropriate assessments and instructional techniques.
- What voice will they have in the decisions being made on the basis of this assessment data?
    - Teachers will collaboratively consider the results and help determine what improvements can and should be made to increase the relevance of the course.

In reading through these questions now, I realize that the anxiety I experienced related to the acceptance of this course by the mathematics teachers in my school was substantial. I did (and still do) have a good relationship with the math teachers, but I was quite concerned that I would not be able to meet their expectation that

I would teach the outcomes from Math 10 C according to their standards. Prior to teaching Scimatics, I had never taught Math 10 C, and I really had no idea what to expect.

While preparing to teach the course, I spent many hours "learning" the content of the Math 10 C Program of Studies. I asked my math colleagues questions when I needed to, asked them for resources and ideas, and shared my contributions with them. To quell my anxiety related to the Math, I focused on addressing the questions I had in a purposeful way through collaboration and reflection. One of the most significant results was that I developed a stronger relationship with the members of the math department. This relationship has continued and I believe has had a positive impact on student learning in the Scimatics course.

My exploration of the literature led to more questions as I began to look for research using the search term "integrated curriculum". This search term provided very few useful articles. However, I found the work of Susan M. Drake particularly useful as it provides a straightforward analysis in a Canadian context. In her article "How Our Team Dissolved the Boundaries" (1991), she describes her work with Ontario teachers on curriculum integration based on thematic instruction. I found it insightful because it led me to want to learn more about the similarities and differences between interdisciplinary, multidisciplinary, and transdisciplinary studies. The broadest questions were: How would I know that integrating curriculum was successful? How would I even define success? and How does one measure quality of learning? As I began to think about how integrated curriculum would apply in my context, the questions became more specific:

- What are researchers saying are the traits of a good scientist?
- What do scientists do?

- What does the research say about being successful students of science? Doers of science?
- What do professors wish high school students knew coming into university classes?
- How can teachers improve efficacy of scientific communication?

I came to realize that what I needed to be looking for was not articles about integrating curriculum, but articles about scientific literacy and how to achieve it. Searching for “scientific literacy” led to many such articles. “Scientific Literacy: A Conceptual Overview” (2000) by Rüdiger Laugksch opened my eyes to several things, the most important of which was the idea that something I thought ought to be simple, defining the term *scientific literacy*, was in fact not. He argues that:

> There are a number of different factors that can influence interpretations of scientific literacy. These factors include the number of different interest groups that are concerned with scientific literacy, different conceptual definitions of the term, the relative or absolute nature of scientific literacy as a concept, different purposes for advocating scientific literacy, and different ways of measuring it. (p. 74)

I realized I needed to understand the concept in a much deeper way than I did, so I used some of the references from his article to educated myself. The works of Paul DeHart Hurd (1998) and Norman G. Lederman (1992) are older, but still relevant. Hurd states that “A valid interpretation of scientific literacy must be consistent with the prevailing image of science and the revolutionary changes taking place in our society” (p. 409). Lederman argues that “the development of an ‘adequate understanding of the nature of science’ or an understanding of ‘science as a way of knowing’ continues to be convincingly advocated as a desired outcome of science instruction” (p. 331). These ideas are still perpetuated in science curriculum documents such as on page 1 of the *Alberta Science 10 Program of Studies*:

> To become scientifically literate, students must develop a thorough knowledge of science and its relationship to technologies and society. They must also

> develop the broad-based skills needed to identify and analyze problems; explore and test solutions; and seek, interpret and evaluate information. To ensure that the science program is relevant to students as well as societal needs, it must present science in meaningful context— providing opportunities for students to explore the process of science, its applications and implications, and to examine related technological problems and issues. By doing so, students become aware of the role of science in responding to social and cultural change and in meeting needs for a sustainable environment, economy and society.

I felt I needed to ensure I truly understood the Nature of Science and scientific inquiry to properly help my students achieve at least some level of scientific literacy. This lead to me to read Roger Bybee's "Towards an Understanding of Scientific Literacy" (1993), George E. DeBoer's "Scientific Literacy: Another Look at its Historical and Contemporary Meanings and its Relationship to Science Education Reform" (2000), Deming et. al's "Scientific Literacy, Resurrecting the Phoenix with Thinking Skills" (2012), Hoolbrook and Rannikmae's "The Nature of Science Education for Enhancing Scientific Literacy" (2007) and "The Meaning of Scientific Literacy" (2009), and Soobard and Rannikmae's "Assessing Student's Level of Scientific Literacy Using Interdisciplinary Scenarios" (2011). All of these articles were useful and informative in their own ways, but they also contributed to my deeper understanding of the meaning of scientific literacy in my high school context. I became convinced that I must focus on the broad ideas of the Nature of Science and scientific inquiry to accomplish my goal.

After countless hours of looking for articles about integrating curriculum and improving scientific literacy, I found myself absolutely exhausted and overwhelmed. What I had thought might be a reasonably simple exercise in reorganizing curriculum outcomes and looking for redundancies between courses, turned out to be a massive exploration into understanding and developing a relevant construct of scientific literacy, and a significant change in pedagogy related to science instruction.

The "How To"

In my experience, there have been four main steps in the procedure: (a) define the construct, (b) build relevant assessment tools, (c) create a construct tool-map (map the assessment tools to the current Program of studies), and (d) refine continually. I will describe my experiences through each of these steps.

Define the Construct

For me, this amounted to reading pertinent journal articles and books to help me define scientific literacy and figure out what level of literacy I wanted my students to gain from the experiences they would have in my classroom. Originally, I wanted to create a course that omitted redundancies (repetitions of outcomes in the math and science Programs of Study), and I eventually did do this, but more importantly I realized that simply omitting redundancies was not what I ought to be focusing on. What I needed to do was help my students achieve a higher level of scientific literacy as well as deeper appreciation for the development of science as a way of knowing.

Although I read the work of many different authors, I was most influenced by the works of Roger W. Bybee, George E. DeBoer, Jack Holbrook and Miia Rannikmae and Jay Lemke. Lemke (1998) states that scientific literacy includes much more that simply a knowledge of NOS and defines it as the ability to "fluently juggle with [a scientific concept's] verbal, mathematical, and visual–graphical aspects, applying whichever is most appropriate in the moment and freely translating back and forth among them" (p. 248). He further suggests that "it is only in the integration of these various aspects that the whole concept [of scientific literacy] exists" (p. 248). Hurd (1998) suggests that as the world changes, so does science, and that a definition of scientific literacy should include the "functional aspects of science/technology as it related to human welfare, economic development, social progress, and the quality of life" (p. 409). He puts forth that "a concept of scientific literacy must recognize the range of changing forces in our society… that includes the ability of optimal use of science/technology knowledge" (p. 410). DeBoer (2000) argues that the definition of scientific literacy in curriculum documents has become too wide. He summarizes the goals of science teaching and the meanings of scientific literacy in nine statements as titled below (pp. 591-593):

1. Teaching and Learning About Science as a Cultural Force in the Modern World.
2. Preparation for the World of Work.
3. Teaching and Learning About Science That Has Direct Application to Everyday Living.
4. Teaching Students to be Informed Citizens.
5. Learning About Science as a Particular Way of Examining the Natural World.
6. Understanding Reports and Discussions of Science That Appear in the Popular Media.
7. Learning About Science for its Aesthetic Appeal.
8. Preparing Citizens Who are Sympathetic to Science.
9. Understanding the Nature and Importance of Technology and the Relationship Between Technology and Science.

He suggests that "we either need to a narrower definition of scientific literacy or that we need to do a better job of addressing all aspects of scientific literacy" (p. 594).

Bybee (1997) describes similar difficulties with a unique definition of the term and offers discussion regarding the apparent inadequacies of the many perspectives which have contributed to *a* definition over the last century. He proposes a framework for scientific literacy which includes thresholds of scientific literacy. His model is one of "inclusion rather that exclusion" (p. 83) as it allows for attainment of levels of scientific literacy which include varying degrees of each aspect of scientific concepts and processes rather than acknowledging only one perspective.

Here, briefly is Bybee's description of the four levels which pertain to K–12 education:

> *Nominal*—an individual understands that a term, question or topic is scientific, but knows little else about it, demonstrates only a token understanding of phenomena.
>
> *Functional*—an individual uses scientific and technological vocabulary, but only within a specific context, knowledge consists of memorized lists of terminology.
>
> *Conceptual and procedural*—an individual understands how the concepts of a discipline relate to the discipline as a whole and to the methods and processes of inquiry; understands and can use ideas such as *observation* and *hypothesis* n laboratory investigations.
>
> *Multidimensional*—an individual understands and appreciates science and technology as cultural enterprises, makes connections within science disciplines, between science and technology, and between science and technology and larger social problems and aspirations in other words, an individual has an interdisciplinary understanding. (p. 83)

Holbrook and Rannikmae (2009) agree that Bybee's four levels of scientific literacy are meaningful for school purposes and that the multidimensional level should be the goal of science education. They suggest it is necessary to relate scientific literacy to "the nature of science, personal learning attributes including attitudes and also to the development of social values" (p. 276). They suggest that there is a need for science education to go beyond the short-term view of obtaining scientific knowledge to a longer-term view of enabling students to "go beyond scientific problem solving to encompass socioscientific decision making, and the recognition that scientific literacy relates to enabling citizens to effectively participate in the real world" (p. 279). It is important to increase the relevance of science education for students by making it more useful to them. They propose approaching the teaching of scientific literacy as "education through science" rather than "science though education" (Table 1, p. 283).

I found it interesting that a common theme expressed by these researchers was a call for science education or curriculum reform which addresses the lack of acceptable levels of scientific literacy being achieved by students in grade school. Most suggest that science should be taught as it relates to society, technology and the environment (the STS movement) rather than a collection of accumulated facts. This is a common concern of science education researchers over time, which indicates that although curriculum reform does occur, the educational experience of our students does not.

After considering the works of the aforementioned authors, I came to this definition for scientific literacy: the ability to communicate acquired scientific knowledge, concepts, and understanding of theories; using appropriate mathematical, visual, graphical, and technological aspects which are most appropriate within the context of a contemporary science related issue. In defining the construct of scientific literacy, it became apparent that the way I looked at curriculum documents needed to be modified. I took on the challenge of finding actual ways to do that. Eventually I came to realize that if teachers are to increase the level of scientific literacy that students achieve, it is the teachers that must change how they teach. I determined that my goal was to change my pedagogy. I needed to change how I presented the curriculum so that students could have more meaningful learning experiences.

Reorganize the Curriculum

Once I defined the construct, I was able to look at the Program of studies in a different light. Instead of seeing outcomes as individual entities like bits of knowledge, specific skills, and neat facts, I began to reorganize them as they were related to and dependent on one another. I took the specific outcomes from Math 10 Common, Science 10, and Chemistry 20, and created a web based on broad concepts rather than subject specific content. For example, the physics component of Science 10 includes the concepts of force, motion, energy conversion, and technological development. As I put my little sticky notes with the outcomes from Science 10 on my board, I realized that I should be including the relevant outcomes from math 10 C and Chemistry 20 as well. Essentially, the entire measurement unit from Math 10 C is essential for communicating any quantity in physics, so, I decided to include that. Then I realized that trigonometry could be useful to help describe direction of motion and to help better prepare students for Physics 20, so I included that. I also realized that linear equations from Math 10 is applicable for graphing motion, so included that too. In terms of time, physics was becoming a much longer unit that it was previously, but math was becoming shorter. The more important thing though, is that math was becoming relevant! These were real applications of measurement, trigonometry, and slope calculations. Rather than finding redundancies, I was finding natural and authentic relationships.

I used this same process for each of the units in Science10 and eventually ended up organizing the outcomes into four disciplines: physics, biology, pure mathematics, and chemistry. I was a little disappointed as I thought I would be moving away from these disciplines and toward thematic units. I realized though, that it was less important to explore creating thematic units, as a thematic approach would limit students to learning about what I was interested in rather than what they were interested in. I decided it was more important to explore how I could achieve making learning relevant within these defined contexts.

This is where I started to think about the assessment tools. Figure 2 is a condensed version of the map I created while re-conceptualizing the curriculum.

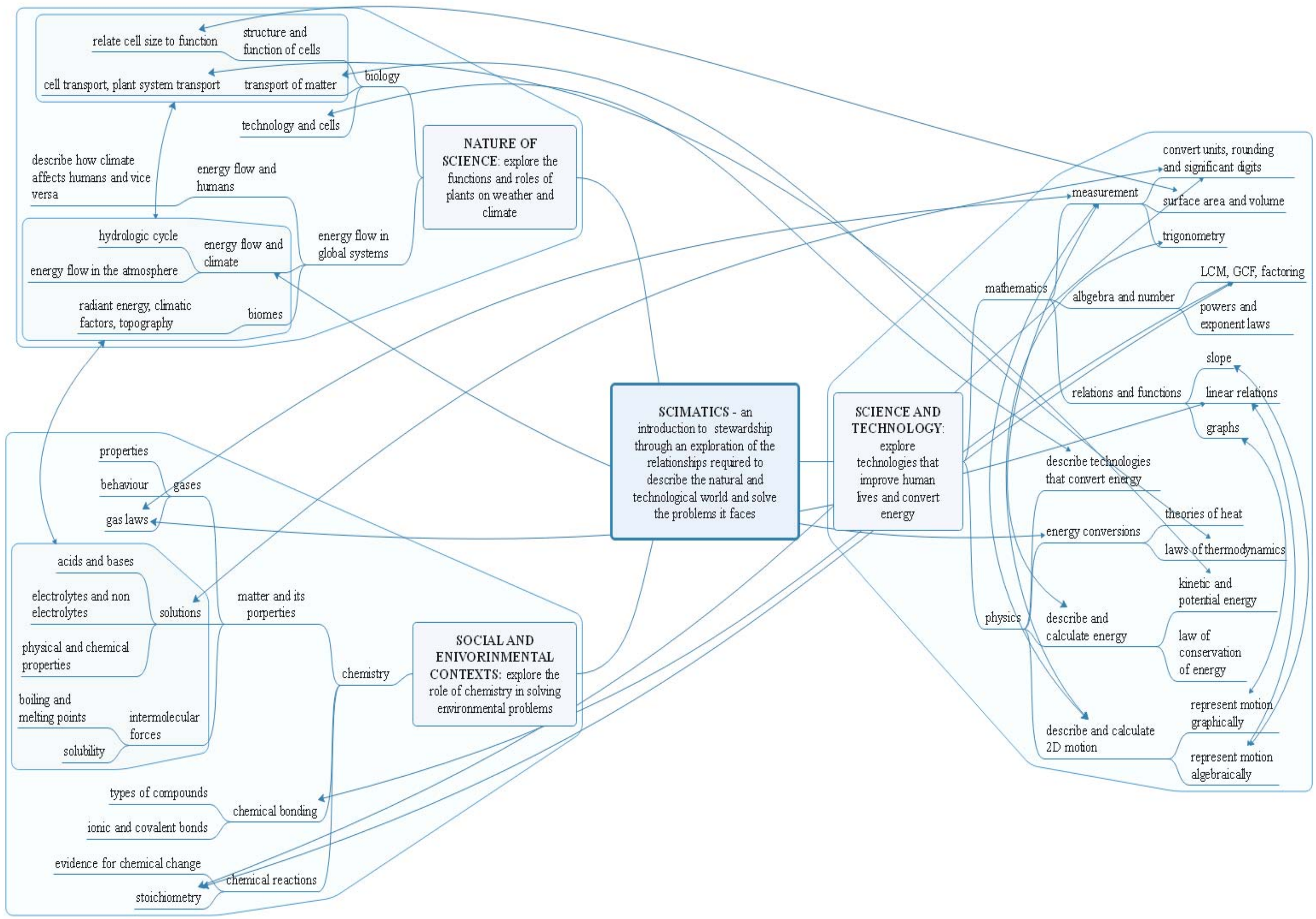

Figure 2. Map of Relationships Between Specific Outcomes from Science 10, Math 10 Common and Chemistry 20

Build Relevant Assessment Tools

With the definition of the construct now clear, it became glaringly evident that the traditional assessment tools I was using were inadequate to promote growth in learning. Tests were good at measuring memorized bits of knowledge about subject matter and scientific theories, lab exercises were good for providing opportunities to learn lab-related skills, but not much attention was being paid to relationship between the nature of science, society, and environmental contexts related to science. In other words, no attention was being paid to the big picture. When I taught Science 10 prior to the development of this course, I showed my students how to use the appropriate mathematical formulas to solve problems and gave them plenty of time to do practice questions from the textbook. I never really related the content to anything outside of the textbook, unless a student asked a question. These types of questions that are "beyond the scope" of the Program of studies were the ones I was scared of as a beginning teacher. I realized though, that these questions are in fact not beyond the scope, but evidence that the student is making a connection with their own previous knowledge or curiosity. I was essentially unable to answer these questions satisfactorily as I did not understand the connections myself. Once I understood what scientific literacy was, though, and that students were just attempting to apply their learning of scientific knowledge, concepts, and theories to science-related issues, I was immediately more willing to investigate them. I became confident that I could tie it back to what the class was "supposed to be learning". This was possible because I had a thorough understanding of the construct of scientific literacy. I reorganized the curriculum in a way that reflected that understanding and was thus confident that I could meet the learning needs of my students and fulfill the requirement of teaching the program of studies. The current Programs of Study for

Science and Mathematics in Alberta do address all aspects of scientific (and mathematical) literacy according to their definitions in each document, but there is more emphasis placed on knowledge than on skills and attitudes. As teachers we tend to focus on those outcomes which dominate the curriculum. As I stated earlier, teachers also tend to ignore the relevance of these disciplines in society and as they relate to technology and the environment. It is likely within the *lived* curriculum that this focus on content knowledge occurs as a result of teachers' level of expertise within their discipline, their experience as a teacher, and their depth of pedagogical knowledge.

Building relevant assessment tools involves determining how to enable students to achieve the desired level of understanding of the construct, while at the same time being respectful of all aspects of the construct. Perhaps the most important change required to accomplish the goal of increasing scientific literacy, is to start with big ideas, then narrow the focus down to bits of knowledge. Recall the distribution of specific outcomes in the Science 10 Program of Studies presented in Figure 1 on page 17. In terms of distribution, there is a much greater value on knowledge outcomes (87 specific outcomes in total) than on skills (45 specific outcomes), attitudes (24 specific outcomes), and STS (20 specific outcomes). Looking at this distribution is problematic if teachers let it influence our planning. We cannot assume that if we make sure to get through all the knowledge specific outcomes that the rest of the specific outcomes will take care of themselves. The ultimate result of planning this way is a devaluation of what makes science captivating, interesting, and worth pursuing.

If one considers the construct of scientific literacy: the ability to communicate acquired scientific knowledge, concepts, and understanding of theories; using appropriate mathematical, visual, graphical, and technological aspects which are most appropriate within the context of a contemporary science related issue, it is apparent that the subconstructs of knowledge, skills and attitudes can be represented as being encompassed by the broader constructs of the nature of science, the relationship between science, technology and society and the environment. Once I had reorganized the curriculum, I created a construct model in which STS encompasses all other curriculum outcomes, as shown in Figure 3 below:

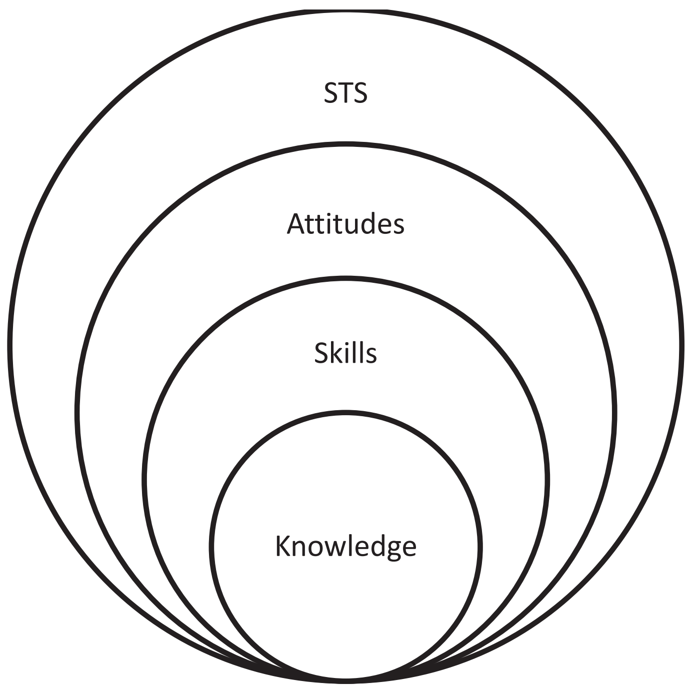

Figure 3. Construct Model for Scientific Literacy

Consider the subconstructs, which in the Alberta Science Program of Studies are called foundations. Knowledge includes the specific bits of knowledge about particular disciplines. The major disciplines in high school science are biology, chemistry, physics and earth science; facts about each of these disciplines can be considered knowledge. The facts in chemistry are different from the facts of biology, and these facts are not necessarily related when presented as belonging to each particular discipline. Skills are transcendant across multiple disciplines and are not limited to the four major disciplines of high school science. In the context of science, skills are the means through which knowledge is confirmed, and thus applicable across disciplines. Attitudes can be described as the lenses through which issues are explored and are certainly applicable in many other disciplines. In the context of science, attitudes inform how the acquisition of knowledge is approached; ideally, with open mindedness. Finally, in my construct model, the STS outcomes *encompass* all the other outcomes, rather than being what the knowledge, skills and attitudes outcomes could be *applied* to.

Once I had re-defined the relationship between the constructs, I realized why teachers have such difficulty improving the level of scientific literacy among their students. I had not been planning in a way to facilitate growth in scientific literacy. My old planning method of teaching the content so they could use the skills related to it—exemplifying and encouraging the desirable attitudes only when they were doing science—and maybe telling them about connections to real life (if I had time), was wrong. I taught from very specific to very broad, but this provides almost no context for those seemingly discreet bits of knowledge. I realized what I needed to be doing was starting very broad and using the STS outcomes to inform the rest of my planning so that the students had context to begin with. I now understand that the STS outcomes are not broad because they *could* apply to everything, but because they *ought to* apply to everything.

The construct model represented in Figure 3 on page 36 organizes curriculum in such a way that teachers start their students thinking about broad contexts and issues. Students are then required to explore questions related to those broad issues with an open mind to construct relevant knowledge by utilizing the skills required to do so. To increase scientific literacy, we must start with all encompassing ideas that provide the foundation for the lens through which we perform skills to *discover* knowledge about the world in which we live. What really solidified my thoughts regarding planning for scientific literacy was when I looked more closely at the front matter of the Alberta Science Program of Studies I realized that the STS foundation was essentially the same as my definition of scientific literacy. Compare my definition with the description of the STS Foundation in table 1 below:

Table 1

Comparison of the Definition of Scientific Literacy with the Description of the STS Foundation from the Alberta Science Program of Studies

Scientific Literacy	STS Foundation (From Alberta Science Program of Study
The ability to communicate acquired scientific knowledge, concepts, and understanding of theories fluently; using appropriate mathematical, visual, graphical, and technological aspects which are most appropriate within the context of a contemporary science related issue.	*Students will* develop an understanding of the nature of science and technology, the relationships between science and technology, and the social and environmental contexts of science and technology.

The ability to communicate scientific knowledge, concepts, and understanding of theories fluently *is* developing an understanding of the nature of science. Using appropriate mathematical, visual, graphical, and technological aspects which are most appropriate *is* developing and understanding of the relationships between science and technology. Appropriate communication of knowledge using relevant communication tools within the context of a contemporary science related issue *is* demonstrating and understanding of the social and environmental contexts of science and technology.

At this point I thought, *why am I not doing this*? The reason was that I never thoughtfully read the front matter of the curriculum prior to creating Scimatics, and even if I had, I am certain I would not have understood what it meant. I knew a lot about science, and chemistry in particular, when I was beginning my career. I taught much as how I had been taught, by delivering subject matter that smarter people had determined was interesting or important. I taught kids stuff, but I didn’t teach them how to figure stuff out. Since I was considering why I never thoughtfully read that front matter in conjunction with the reading and learning I was doing related to construct development, I came to the following supposition: perhaps teacher preparation programs do not provide sufficient emphasis on reading and understanding the underlying philosophies of the program of study to student teachers. In my personal experience as a student teacher, and in working with student teachers today, most emphasis is placed on detailed lesson planning with particular importance on specific outcomes, time management, and student behaviour management. Thus, student teachers are prepared to teach content in specified blocks of time organized in such a way to reduce possible behaviour issues. Determining a singular reason for this level of preparedness is far beyond the scope of this paper as this issue is of course far more complex than the curriculum of any teacher education program. However, it is important to reflect on why I only began to think about the importance of the underpinnings of scientific literacy a decade into my practice rather than at the beginning of my career. Perhaps I was never made to philosophically consider scientific literacy as a student teacher. Or I was asked to study it, and was not interested in learning it. Or perhaps I did learn it, but it was not memorable enough for me to remember it. The definite reason why *I* didn't learn the importance of scientific literacy is not actually important. What is important, however, is that scientific literacy is not treated as the most important construct of science education (Lemke, 1998).

I further surmised that curricular reform may not be succeeding because preservice teacher education programs and teacher professional development do not sufficiently address the introductory matter to the Program of Studies to prepare new teachers to read and understand it well enough to implement the curriculum as intended. If the expectation is that students ought to graduate from high school with the tools they need to make informed decisions, then they must be able to process and communicate information from many perspectives. This type of processing and communication requires not only high levels of literacy in multiple disciplines, but also the ability to recognize the importance of the relationships between disciplines. Hopefully, this project on the development and implementation of Scimatics will provide some insight into how teachers can get to this mind-shift.

Conceptualization of the construct is essential to assessment development. This allows one to focus on the big picture and identify the relationships between curriculum, instruction and assessment. Once the instructor has a clear understanding of what they want their students to be able to articulate, then they can begin to develop some assessment tools. I decided that it was important for my students to have to capacity to develop what Bybee calls the multidimensional level of scientific literacy described earlier in this paper (1997, pp. 37-68).

- **Nominal**—individuals associate names with a general area of science and technology

- **Functional**—individuals respond adequately and appropriately to vocabulary associated with science and technology
- **Conceptual**—individuals demonstrate and understand both the parts and the whole of science and technology as disciplines and they can identify the way new explanations and inventions develop vis à vis the processes of science and technology
- **Multidimensional**—individuals understand the relationship of disciplines to the whole of science and technology to society

To achieve that level of scientific literacy I would have to use assessment tools that challenged my students to think beyond the curriculum and make deliberate and explicit connections between their work and what they were learning in class. I would have to focus a great deal more on STS than I had in the past. Today, scientific research is often driven by societal and environmental needs and issues. These issues are often part of the political agenda. Students' conceptions of scientific research are often developed because of listening to or reading the news or participating in discussions with family and friends. I thought that if students were allowed to take a deeper look at the issues in which they may already be interested, then they would gain more knowledge about both that issue and science in general. This excerpt from the Alberta Science Program of Studies is good guidance: "The potential of science to inform and empower decision making by individuals, communities and society is a central role of scientific literacy in a democratic society" (Alberta Education, 2005). What assessment tools can be used to encourage students to make decisions based on their growing scientific literacy? Certainly not the paper and pencil tests I had been using. I decided to explore science fair projects, research projects, posters, and presentations. The tools I would use to assess my students would have to be more respectful of the construct; they would have to allow students to communicate their constructed knowledge. I would have to use visual representations, written reports, verbal explanations, lab notebooks, and interviews to determine whether students were achieving any level of scientific literacy.

When I spoke to my colleagues about it, they thought it was a great idea, but expressed that they would never do it as they could not sacrifice the little class time they had and did not believe it would be worth the extra planning time required to determine which outcomes were being met. This was something I considered for quite a while. How would I determine which outcomes were being met? If I chose what the students would focus on, I would limit or remove their ability to focus their learning on something they were interested in. This was not what I wanted to do. I went back to my construct and focused on the relationship of scientific literacy with the STS outcomes and realized that if I was focusing on the three dimensions of STS (Nature of Science, Science and Technology, and Social and Environmental Contexts of Science and Technology), then I could determine if they were acquiring the skills and attitudes related to scientific literacy since my definition of scientific literacy is echoed in the STS foundations of the Program of Studies. I mapped each one of the possible assessment tools to the STS outcomes and determined that this was indeed where I needed to focus my time on developing assessment tools. This is important because it gives me, the teacher, a direct correlation between what I am using to assess my students and a means to report what they have communicated they have learned through the assessment.

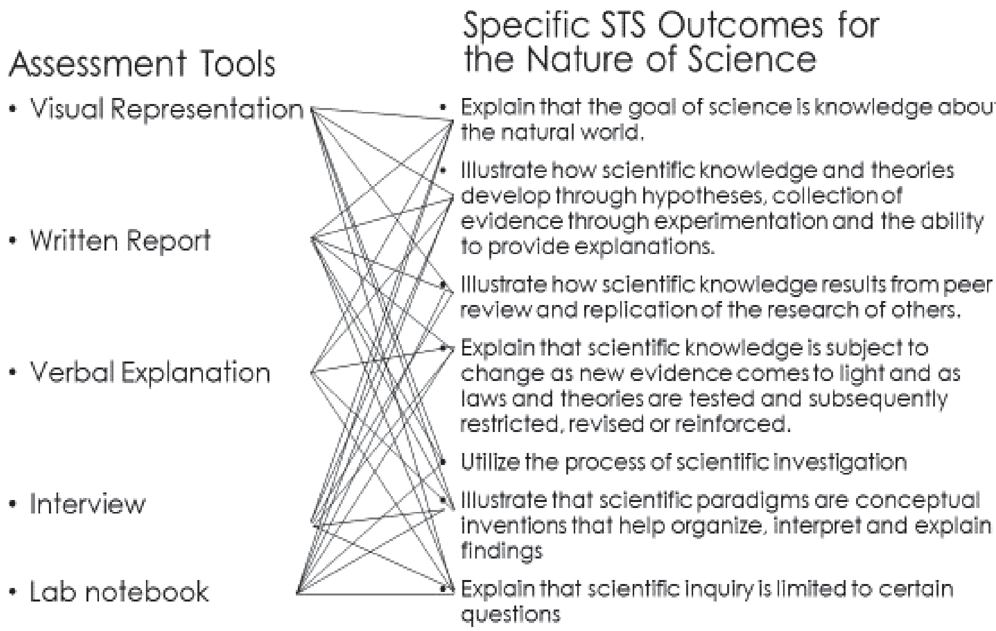

Figure 4. Construct Tool Map for the Nature of Science

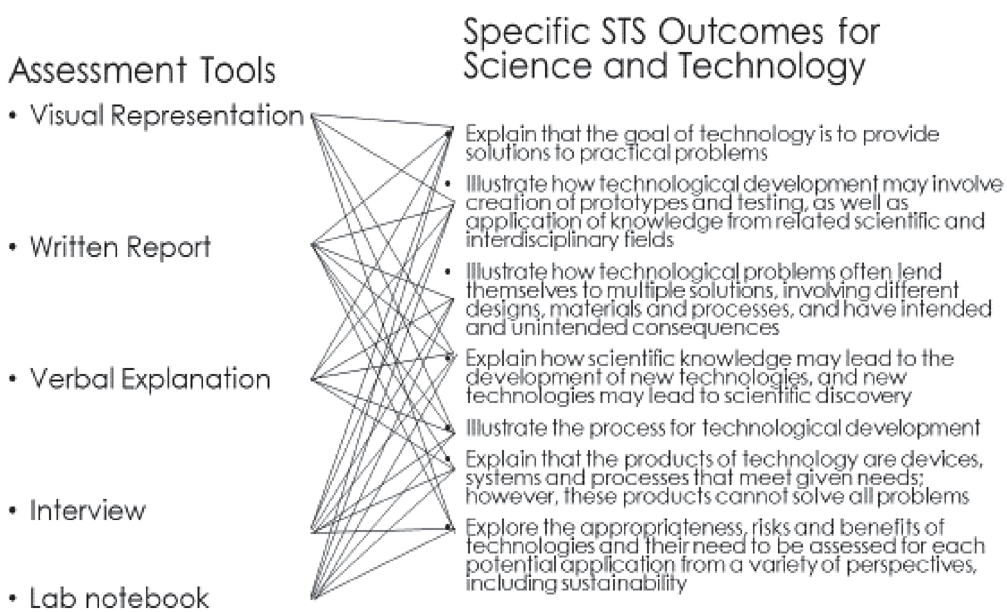

Figure 5. Construct Tool Map for Science and Technology

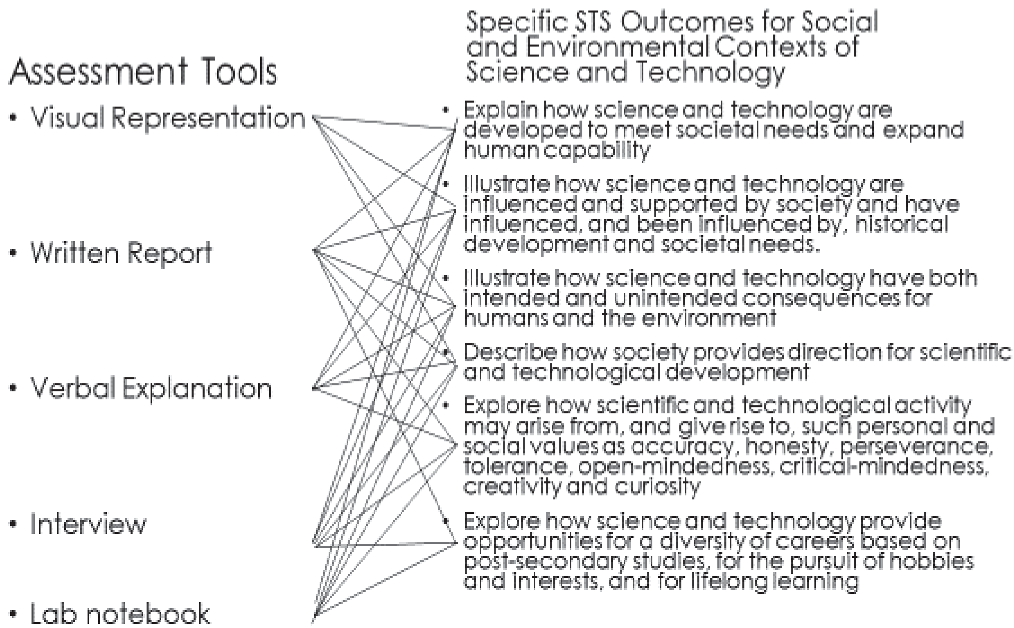

Figure 6. Construct Tool Map for Social and Environmental Contexts of Science and Technology

It is clear that each of the assessment tools will fulfill the requirements of scientific literacy. I was also adamant that if students were going to use projects to increase the level of scientific literacy that they achieved, then they would have to have choice in what they wanted to learn about. This was a big struggle for me.

Normally, when we plan a project, we choose the outcomes that are going to be addressed during the course. However, I did not want to limit my students to certain specific outcomes as that would put constraints on the depth of learning they could do through the project. This is where I needed courage more than I ever had in the classroom. I knew I had to let my students choose what they wanted to do and I needed to trust that they would still be learning the prescribed curriculum. The work of Lorrie A. Shepard (2000) has had the most profound influence on how I teach and assess to help my students achieve increased levels of scientific literacy. Her words regarding the social-constructivist method of learning kept rolling around in my mind: “School learning should be authentic and connected to the world outside of school not only to make learning more interesting and motivating to students but also to develop the ability to use knowledge in real-world settings” (2000, p. 7). Shepard also proposes:

> To be compatible with and to support this social-constructivist model of teaching and learning, classroom assessments must change in two fundamentally important ways. First, its form and content must be changed to better represent important thinking and problem solving skills in each of the disciplines. Second, the way that assessment is used in classrooms and how it is regarded by teachers and students must change. Furthermore, to enable this latter set of changes within classrooms, I argue that teachers need help in fending off the distorting and de-motivating effects of external assessments. (p. 7)

To me, this means that assessment ought to be regarded as an activity for learning or as a process of learning, not just a measurement of learning. This is extremely liberating, since essentially it means we can use assessment tools without grading them and can put more emphasis on formative assessment rather than summative assessment. This requires that students participate in assessment as learning without being motivated by grades. Shepard agrees:

> To accomplish the kind of transformation envisioned, we have not only to make assessment more informative, more insightfully tied to the learning steps, but at the same time we must change the social meaning of evaluation. Our aim should be to change our cultural practices so that students and teachers look to assessment as a source of insight and help instead of an occasion for meting out rewards and punishments. (p. 10)

If I had to choose one statement that embodies my vision of assessment this is it. This is how genuine learning occurs, by treating assessments as relevant learning opportunities. I believe that the purpose of assessment is for learning and that we should be respectful of the impact assessment tools have on learners. We must be explicit about the reasons we use assessment tools, involve students in the process of assessment, and allow students to choose issues which are personally relevant to them when learning. Not only does this create a culture of learning in the classroom, it also functions to motivate students to learn and provides them with a reason to spend time on something that is not for grades and not explicitly intended to help them score well on diploma exams.

The Tools

The development of the actual tools has been a multi-year long process for me, hence the final step in the implementation of Scimatics—continual refinement. Continual reflection, collaboration with like-minded colleagues, and utilizing feedback from students has been necessary for the improvement of the functionality of these tools. I have taught Scimatics for four years now and each year these tools have been modified to improve their efficacy. Initially, I had tried to create a research project that would last all year and encompass the entire course. It was supposed to culminate in a project for the city's science fair. I abandoned this idea after the first year because it was far too much for me to manage and the students found it difficult to maintain their interest over the long periods of time in between working on it. Earlier I reasoned that rather than developing overarching themes, I would keep with the traditional disciplines of physics, biology, chemistry and pure math in this course. This alleviated the anxiety of my colleagues who were concerned that students would not know what they were learning and have difficulty moving on to the next level. It also gave me an opportunity to create assessment tools that function as bridges between disciplines as students breach the barriers between them to create meaningful learning opportunities. I should also state that I still use traditional summative classroom assessments like quizzes and tests which are for marks, as a measurement of learning. The focus of the projects is assessment for and as learning.

The course sequence is as follows: physics, math, biology, chemistry (see Appendix A). The assessment tools are projects which span the weeks during which we explore each science discipline. I describe each one briefly below. See Appendices B, C and D as example for detailed outcome mapping. For physics, the students create a poster which describes the development of a technology of their choice from its inception until present time. For biology, students create an infographic, write a short essay, and they write a critical essay which answers the question: What do plants do? For chemistry, students choose an environmental issue for which the solution could be based in chemistry and present their research project in a science fair format[1].

Physics (STS Focus: Science and Technology)

Students begin the physics unit with the technology poster project. We watch the Discovery Channel advertisement with the song "I love the Whole World", then we talk about all the technologies and advancements in the ad. It is a wonderful discussion and I love to see their faces light up when we talk about how fortunate we are to be able to see and do all the things we can in this world. They choose any technology they are interested in and create a poster which traces the development of their chosen technology from its inception until present time. Examples I have had the pleasure of learning about through their projects are time-keeping devices, shoes, printers, rockets, braces, books and pencils. As we go thought the lessons, students add pertinent information they learn in class to their poster. The focus of the physics unit is on science and technology; therefore, one of the important pieces of information they add is why the technology changed over time. They must explain whether improvements were made due to advancements in other

[1] I have also done a reflection journal for the mathematics section on the applicability of mathematics in real life. However, I did not include it in this paper as the focus here is on scientific literacy.

technology, new scientific discoveries, or whether society demanded improvement. As we move through the lessons and learn the specific knowledge outcomes, students are required to identify where these concepts are applicable in their own technology. Rather than me looking at each project and determining what outcomes the students are meeting, they do it themselves, thus making relevant connections between classroom learning and real life. As part of the physics unit students also learn measurement, unit conversion, slope calculations and trigonometry which are found in the Mathematics 10 Common Program of Studies. They are required to include these concepts on their poster as well. Given that there are 25 knowledge specific outcomes in physics and 15 specific outcomes in math that are addressed in this unit, it seems this may be too much to ask of the students. Indeed, I thought it was at the beginning. However, at the end of the unit, when the students present their posters to the class and answer questions from their classmates, virtually every specific outcome is addressed in some way. For example, I had no idea that the ridges on the soles of basketball shoes can be designed based on take-off angles related to velocity of a moving player when they are jumping. And although this may not be entirely true, certainly some thought has gone into the angles of those rubber ridges. The beautiful thing, though, is that grade 10 students realize that there is connection between velocity, friction, momentum and height, something they do not really explore until later physics courses. What they learn from this experience and the confidence they gain prepares them for future presentations. I also really appreciate how other students ask genuinely good questions; questions that demonstrate they are curious about what their classmates are telling them, rather than about simply clarifying what they are saying. They keep each other on track and on task as they all struggle though finding the connections. We display the posters in the hallway usually for the duration of the unit so the class sees how they are all added to and give each other feedback along the way. I have also had several teachers and administrators come in and ask me or my students what the posters are about which gives the students opportunities to talk about their chosen technology from an unprepared state. It is especially encouraging to hear them answer these spontaneous questions as it demonstrates the level of scientific literacy they have achieved. I do not grade the posters or the presentations and the students are well aware that this is the case. With each step I explicitly tell them the reason they are adding to the poster. I also use their posters as examples to teach a concept we are learning in class. I usually see groups of students gathered around posters asking questions directly related to physics as they prepare for the exam.

Biology (STS Focus: Nature of Science)

Before I taught Scimatics, I really disliked teaching the biology section of Science 10. I felt it related to nothing and was just a bunch of stuff to memorize. It was painful. Now, however, I very much look forward to it. The focus of the biology unit is life processes and the structure of plants. I have tied the unit on energy flow in global systems into biology (and also thermodynamics as part of physics) since plants have a major role in global climate, which involves thermal energy transfer. It is so much fun to discuss why we have some mathematical formulas (thermal energy transfer, surface area and volume), why failure is important for growth, and how plants contribute to life on earth and the globalization of food. We start the unit by drawing a plant that has roots, a stem and a few leaves in the center of a blank paper. Then students answer the question "What do plants do?" in a SEE-I format (State, Explain, Elaborate or Example, Illustrate). They end up doing the SEE-I twice—once at the beginning of the unit and once at the end—to demonstrate growth in thinking. The first time is usually a quarter to half a page long and not very thoughtful. The second time, students write anywhere from one to five pages and I am always moved by their growth and passion for life. It is my favorite assignment to look at… and I do not grade it.

With the plant, students create an infographic. As we go through the lessons, students add information to their page about microscopes, cells and organelles, plant tissues and functions, plant organs and systems, as well as plant responses to various stimuli. It ends up being very dense and overwhelming, so their final task is to re-do the infographic as concisely as possible. I realized that by letting them reflect on, reconsider, and re-write the information in as few words as possible, that they were actually learning it better. So now, I set aside a whole class period for them to do this. I have found this works best with an imaginary plant so that they are focusing on the concepts rather than the specific aspects of a particular plant. Once we have gone through the material from the global systems unit, they write a short essay which justifies the biome in which their plant belongs and a peer reviews it for them. We do the peer review several times so that students are able to examine more than one biome in detail and so that they get used to having someone review their work. They are to give feedback specifically on ideas and not spelling and grammar. What would they like to read more about? What needs clarification? Why did you think this was important? I do not read the peer commentary unless a student asks me to. But when they hang their posters in the hallway and we circulate around asking them questions about the biome their plant belongs in and why, I am always deeply impressed with their answers[2]. The infographic is used by the students

[2] This past year I had a wonderful opportunity to team teach Scimatics with the biology teacher. We had 57 students who wanted to take the class and our principal allowed us to offer a congruent class which combined Science 10 and Biology 20. We taught the physics and biology sections together with all 57 students. It was the most fun I've had in my teaching career. My colleague was able to continue on with the Infographic and essay about biomes and expand those projects into her biology course. What her students

for review for their unit exam, and the essay describing the biomes in which their plant lives gives them an opportunity to demonstrate how they make connections between disciplines (biology, earth science, chemistry). Most students allow me to keep these projects as examples for future classes, which has greatly improved the quality of projects I get from year to year. When I survey my students at the end of the year I ask them what they liked best about the course, and generally, they say the plant project. Interesting that their favorite thing is something they spend hours on and do not get marks for.

Chemistry (STS Focus: Nature of Science and Social and Environmental Contexts)

I love chemistry. It is what I studied in university and I love the challenging problem-solving nature of the discipline. We start the unit off by looking at our plant infographics and essays on biomes and discussing potential environmental issues related to plants and global climate. Students choose an environmental issue for which the solution could be based in chemistry and we put the issues and ideas up un a display board in the classroom. I like to have the students' ideas where I can see them so that it reminds me to refer to them as I am teaching, thus pointing put connections to real life as often as possible. I do the same with the technology posters and the infographics so that I have a constant reminder of why I am doing what I am doing. The chemistry unit usually takes about 14 weeks to get through, so this project is long. We talk about choosing issues they are passionate about and will not get bored of because they will be with it for a long time. This gives them a little taste of what it is like to do research. I usually give them some time every couple of weeks to work on this project, but it is mostly on their own time since the connections are not as explicit as they are in the physics and biology

did with them and their ability to tie what they learned in Science 10 to Biology 20 was amazing. She told me that students were finally seeing the relevance of science 10.

units. At first I thought this was too much of a stretch, that letting them choose any environmental issue was a sure way to lose the connection between the classroom and real life; but in truth, the nature of chemistry is discovery, and if I allow them to discover how chemistry can be used to help our planet, then I am not detracting from the construct and students are truly stretching themselves. Near the end of the year, they present their research project in a science fair format. Invariably, I am awe struck at the depth some students are able to go to and the confidence with which they present. Some of the quietest students in the class are often the most confident in the presentation. In fact, I am hearing on the news today about some of the issues my students presented about years ago. Two years ago a couple of young ladies presented their research on the harmful effects of certain sunscreens on coral. They proposed banning the use of regular sunscreen and using mineral sunscreens instead, although the cost could be quite prohibitive. This summer, I have heard that Hawaii plans to ban certain sunscreens and I have seen several new and more economical choices for mineral sunscreens. It is very exciting to give students the opportunity to be immersed in current issues and to hear them talk about them from a scientific perspective outside of the classroom.

We wrap up the course with a final exam on chemistry that students spend hours studying for in the last few weeks of school. They generally do not remember anything about that final exam when I see them the next year (or two years later) in Chemistry 30. But they do remember the technology poster, the plant project, and their chemistry research project. Often times they tell me they used part of their research in a Social Studies project, or in an English essay. Nothing makes me happier than hearing these stories. I hope one day to make formal projects that students can use in more than one class to further develop their capacity to think in multiple disciplines and integrate their knowledge in meaningful ways.

Conclusion

The journey to create, develop and implement an integrated curriculum course has been long and in the end, an enjoyable one. Certainly, the best years of my professional career have been dedicated to Scimatics and to the students who take it. I am proud of them as young people for learning to articulate and communicate scientific ideas, theories and concepts though multiple modalities, confidently and proficiently. As I read the conclusion of Lorrie Shepard's "The Role of Assessment in a Learning Culture" I hope that I have challenged her acknowledgement that her "social-constructivist view of classroom assessment is an idealization" (p. 12). It can work. It does work. Reconceptualizing curriculum is not as daunting as it once seemed to me. Realizing the importance of defining a construct and subsequently acknowledging the importance of grounding curriculum in that construct and reorganizing learning outcomes so that they make sense within it is a liberating experience. I am so much more confident in my pedagogy and so much less concerned with standardized tests that I have been able to explore assessment on a completely different level and make it fun to learn in a high school science classroom. I hope more teachers will have the courage to create innovative courses like Scimatics. I hope that more of us plan with the end in mind and that it is understood that the end is in fact not an exam, but a higher level of attained literacy in whatever discipline we are teaching. I hope that we are able to teach because we are experts at making connections between what we know a lot about and what we know less about. And finally, I hope we are able to inspire our students to do extraordinary things in their lives after high school.

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Appendix A

Scimatics Course Sequence

Week	Content Topic	Assessment Tools	Monday	Tuesday	Wednesday	Thursday	Friday
1	Measurement Physics Trigonometry Slope	**Technology Poster:** - students choose any technology and make a timeline of its development - students identify why changes occurred (scientific, technological or societal) - students identify which curriculum outcomes relate to their technology (S10, M10) - students present their posters		-course expectations	- technology research	- why/how measure?	- fundamental units
2			- 1.1: referents	- 1.1: SI system and conversion within	- 1.2: imperial system and conversions within	- 1.3: conversions between SI and imperial systems	- review
3			- Measurement test	- steam engines – relate to technology - theories of heat	- work, force, energy -graphical work - SA basic shapes	- graphical work non-uniform -specific heat capacity	- heat, thermodynamics - review
4			- review	- Chapter 4 Test including imperial, SI, SA basic shapes	- scalar/vector - distance/displacement - introduce trig ratios	- 3.1-3.3: Pythagorean theorem and SOH CAH TOA	- 3.1-3.2: SOH CAH TOA - 3.3: solving triangles - interpreting vectors
5			- review trig and vector analysis	- quiz	- speed and velocity - graphing speed and slope	- acceleration	- graphing acceleration - kinetic energy
6				- kinetic energy - potential energy - mechanical energy	- mechanical energy - review	- Chapter 5 test	- Chapter 5 test
7			- efficiency - energy conversions and the environment	- review	**PHYSICS EXAM** (includes measurement and trigonometry)	**PHYSICS EXAM** (includes measurement and trigonometry)	

8	Linear Relations and Functions	**Journal: Math in Science** - students write a reflective journal once a week and discuss their ideas about how they see math in relation to science	- 6.1: Graphs of relations	- 6.2: Linear relations	- 4.4: rational and irrational numbers - 6.3: domain and range	- 6.4: functions	- 6.5: slope
9	Linear Equations and Graphs		- review	- Chapter 6 test	- 7.1: slope intercept form	- 7.2: General form	- 7.3: slope-point form
10	Linear Equations and Graphs		- 7.4: parallel and perpendicular lines	- review	- Chapter 7 test		
11	Solving Systems of Equations		- 8.1: systems and graphs	- 8.2: modelling and solving	- 8.3: number of solutions	- 9.1: solving by substitution	- 9.2: solving by elimination
12	Solving Systems of Equations		- 9.3: solving problems	- review	- Chapter 8+9 test	half day	
13	Radicals		- 4.1: square and cube roots	- 4.2: integral exponents	- 4.3: rational exponents	- 4.5: mixed and entire radicals	- review
14	Polynomials		- review	- Chapter 4 test	- 5.1: multiplying polynomials	- 5.2: common factors	- 5.3: factoring trinomials
15	exponents		- 5.4: factoring trinomials	- 5.5: factoring special trinomials	- review	- Chapter 5 test	- 2.1: SA prisms and cylinders
16	exponents		- 2.2/2.3: SA pyramids, cones and spheres	- 2.4: V prisms, cylinders, spheres	- 2.5: V cones and pyramids	- review	- Chapter 2 test
17	Global Systems and Climate	**Infographic:** - students draw a simple plant with roots, stem and leaves - add information to their page as they learn it and	- global systems and solar energy	- thermal energy transfer, phase changes, distributing heat	- climate and biomes	- climate change	- presentations
18	Cells		- diversity of cells and microscope	- microscope lab	- cells	EXAMS	EXAMS

		eventually create an infographic which includes all outcomes	EXAMS	EXAMS	EXAMS	EXAMS	EXAMS
19	Cell membranes	- students justify which biome their plant would be in and explain how plants contribute to global climates	EXAMS	-review	- quiz	- membrane properties	- transport across membrane
20	Cell membranes, transport, plant control systems		- cell size SA/V	-review	-quiz	-cell specialization	- gas exchange - water transport
21		**SEE-I: What do plants do?** - do this on day 1 and again before exam (evidence of student learning)	- plant control	- review - tie back to biomes, climates	-review	-Biology Exam	GOOD FRIDAY
			EASTER BREAK	EASTER BREAK	EASTER BREAK	EASTER BREAK	EASTER BREAK
22	Sci 10 Chem	**Research Project:** - students choose an environmental issue and research the problem then proposed a solution (having to do with chemistry if at all possible) - present as science fair project	- matter	- elements	- atomic theory	- classifying compounds	- molecular compounds
23			- ionic compounds	- acids/bases/water	- the mole concept	- identifying reactions	- types of reactions
24			- types of reactions	- balancing reactions	- review	- test	
25	Chemical Bonding		- ionic bonding	- ionic compounds	- molecular compounds	- Lewis theory	- structural formulas
26			- VSPER theory	- shapes	- polarity	- polarity	
27			- IMF	- IMF	- properties of solids	- review	- test
28	Gases		- properties	- Bolye's law	- Charles' law	- combined law	
29				- molar volume - properties	- ideal gas law	- review	- Chemical bonding exam
30	Solutions		- solutions/ mixtures	- explaining solutions	- solubility	- solution conc	- solution conc

31			- preparing solutions	- preparing solutions	- lab	- review	- test
32			- properties of acids/bases	- pH/pOH calcs	- indicators	- explaining acids/bases	
33				- strength of acids/bases	- review	- test	- review of reactions
34	Stoichiometry		- gravimetric stoic	- gravimetric stoic	- gas stoic	- solution stoic	- solution stoic
35			- limiting/ excess	- limiting/ excess	- review	- test	
36			- titration	- titration curves	- test	- review	- review

Legend: Yellow = Physics, Pink = Math, Green = Biology, Purple = Chemistry, Red = No School

Appendix B

Physics Project Overview for Teachers

PHYSICS PROJECT DESIGN: OVERVIEW						
Name of Project: The Changing Face of Technology						**Duration: 5 Weeks**
Subject/Course: Scimatics						**Grade Level: 10**
STS Focus: Science and Technology Technology is concerned with solving practical problems that arise from human needs. Historically, the development of technology has been strongly linked to the development of science, with each making contributions to the other. While there are important relationships and interdependencies, there are also important differences. Whereas the focus of science is on the development and verification of knowledge, the focus of technology is on the development of solutions, involving devices and systems that meet a given need within the constraints of a problem. The test of scientific knowledge is that it helps us explain, interpret and predict; the test of technology is that it works—it enables us to achieve a given purpose.						
Subject areas to be included: Physics, Mathematics						
Cross Curricular Competencies, Attitudes*, and Skills** These competencies, attitudes and skills are applicable beyond the curriculum	Critical Thinking	x	Interest in Science*	x	Cultural and Global Citizenship	
	Communication**	x	Scientific Inquiry*		Personal Growth and Well-Being	
	Collaboration**	x	Managing Information	x	Stewardship*	
	Creativity and Innovation		Problem Solving		Safety*	
	Initiating and Planning**		Performing and Recording**	x	Analyzing and Interpreting**	x
Project Summary (include student role, issue, problem or challenge, action taken, and purpose)	Students choose a technology that they are interested in and describe its development over time. As we work through the course content, they will add pertinent information to their timelines. Eventually, they will present a poster that describes their chosen technology and how concepts of physics and mathematics are relevant to it. They will also identify how societal needs, scientific discovery, and perhaps environmental issues have affected the development of the technology.					
Driving Question	How and why do technologies change over time?					
Entry Event	Watch Discovery Channel video *I love the Whole World* (Parts 1 and 2) Discuss how many technologies are in the video… and how the video and images could not be recorded without technology					
Products	Individual/Team: Poster/Oral presentation	Cross curricular competencies to be addressed: Critical thinking, Collaboration, Managing Information, Communication				

PHYSICS PROJECT DESIGN: OVERVIEW

Making Products Public (include how the products will be made public and with whom students will engage during/at end of project)	Classmates, Student Body, Teachers, Other Staff – Posters will be displayed in the hallways as students work on them so everyone will be able to see them.			
Resources Needed	On-site people, facilities: Wall space, collaborative classroom space			
	Equipment:			
	Materials: poster paper, felt pens			
	Community Resources:			
Reflection Methods (how individual, team, and/or whole class will reflect during/at end of project)	Journal/Learning Log		Focus Group	X
	Whole-Class Discussion	X	Fishbowl Discussion	X
	Survey		Other:	
Notes:				

PHYSICS PROJECT DESIGN: STUDENT LEARNING GUIDE

Project: The Changing Face of Technology

Driving Question: How and why do technologies change?

Concepts (focus on how scientific knowledge is developed)	**Skills** (focus on scientific inquiry)	**Final Products** (where evidence of learning will be)	**CCCASs**[3] Which CCCs are fostered? Possible learning experiences
the goal of technology is to provide solutions to practical problems (ST1)	- identify questions to investigate arising from practical problems (IP–ST1)	Poster Presentation Q&A	Collaboration Communication Initiating and Planning Interest in Science Manage Info Problem Solving Stewardship Analyzing and Interpreting
	- research, integrate and synthesize information from various print and electronic sources relevant to a practical problem (PR–ST1)		
	- evaluate designs and prototypes on the basis of self-developed criteria; e.g., function, reliability, cost, safety, efficient use of materials, impact on the environment (AI–ST1)		
	- work collaboratively to test a prototype device or system and troubleshoot problems as they arise (CT–ST1)		
technological development may involve the creation of prototypes, the testing of prototypes and the application of knowledge from related scientific and interdisciplinary fields (ST2)	- propose and assess alternative solutions to a given practical problem, select one and develop a plan (IP–ST2)	Presentation	Critical Thinking Communication Problem Solving Analyzing and Interpreting
	- construct and test a prototype device or system and troubleshoot problems as they arise (PR–ST2)		
	- analyze alternative solutions to a given problem, identify potential strengths and weaknesses of each and recommend an approach to solving the problem, based on findings (AI–ST2)		
	- select and use appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions (CT–ST2)		
technological problems often require multiple solutions that involve different designs, materials and processes and that have both intended and unintended consequences (ST3)	- evaluate and select appropriate procedures and instruments for collecting data and information and for solving problems (IP–ST3)	Poster Presentation	Collaboration Communication Managing Info Personal Growth
	- select and use tools, apparatus and materials safely (PR–ST3)		
	- solve problems by selecting appropriate technology to perform manipulations and calculations (AI–ST3)		
	- evaluate individual and group processes used in planning and carrying out problem-solving tasks (CT–ST3)		

[3] CCCASs = Cross Curricular Competencies, Attitudes and Skills

scientific knowledge may lead to the development of new technologies, and new technologies may lead to or facilitate scientific discovery (ST4)	- identify new questions and problems that arise from what was learned and evaluate potential applications of findings (AI–ST4)	Poster Presentation Q&A	Creativity and Innovation Citizenship Scientific Inquiry Citizenship Stewardship Analyzing and Interpreting
the process for technological development includes (ST5): – defining and delimiting, clearly, the problems to be solved and establishing criteria to assess the technological solution (ST5a) – identifying the constraints, the benefits and the drawbacks (ST5b) – developing designs and prototypes (ST5c) – testing and evaluating designs and prototypes on the basis of established criteria (ST5d)		Poster Presentation Q&A	Creativity and Innovation Citizenship Interest in Science Scientific Inquiry Citizenship Stewardship Analyzing and Interpreting
the products of technology are devices, systems and processes that meet given needs; however, these products cannot solve all problems (ST6)		Poster Presentation Q&A	Creativity and Innovation Citizenship Interest in Science Scientific Inquiry Citizenship Stewardship Analyzing and Interpreting
the appropriateness, risks and benefits of technologies need to be assessed for each potential application from a variety of perspectives, including sustainability (ST7)		Presentation Q&A	Creativity and Innovation Citizenship Interest in Science Scientific Inquiry Citizenship Personal Growth Stewardship Analyzing and Interpreting

PHYSICS UNIT PROJECT: DELIVERY GUIDE

Project: Technology Poster

Unit: Physics

Driving Question: How and why do technologies develop over time?

Teacher Focus: The goal is to inspire students to consider the importance of technological development.
Talk about how technology development is unique to humans and explore why that is.
The teacher's passion about technology will instill an insatiable curiosity in one of your students to continue to study science in some way.

Important: This project is not a stand-alone learning activity or assessment tool. It is built upon for the duration of instruction of unit B (Energy Flow in Technological Systems) from the Science 10 Program of Studies.

	Learning Activities	Timing	Content Knowledge	Project Work
1	**Choose a technology:** Can be ANY technology!	Beginning of unit or after the measurement unit	None so far!	Timeline depicting development of chosen technology.
2	**Add reasons for change or improvement to timeline**	After • Teaching about the relationship between science, technology and society	• Technological innovations that led to the development of the concept of energy	Describe improvements made to chosen technology as being driven by technological innovation, scientific discovery and or societal need
3	**Add measurement information**	After • Teaching measurement	• Fundamental units and derived units	Describe what is or can be measured with chosen technology
4	**Add work**	After: • Teaching about work	• work	Describe where work is done with the technology
5	**Add theories of heat and laws of thermodymics**	After • Teaching theories of heat and laws of thermodynamics	• Theories of heat • Laws of thermodynamics	Describe where theories of heat apply Describe how the first and second laws of thermodynamics apply

6	**Add description of motion**	After • Teaching one dimensional motion	• Scalar/vector • Unit conversion	What type of motion is involved with chosen technology?
7	**Add Trig**	After • Teaching trig	• Sine, cosine and tangent ratios	Is there trigonometry involved in the technology
8	**Add speed and velocity**	After • Teaching speed and velocity	• Speed and velocity • Slope calculations	Would either of these concepts apply within your technology?
9	**Add acceleration**	After • Teaching acceleration	• Acceleration • Graphing acceleration	Is acceleration applicable?
10	**Add kinetic energy**	After • Teaching kinetic energy	• Energy related to motion	Are there moving parts in your technology? How much kinetic energy is required to use your technology? Or does it produce kinetic energy?
11	**Add potential energy**	After • Teaching potential energy	• Gravitational potential energy • Chemical energy • Elastic potential energy	Does your technology use or create potential energy?
12	**Add efficiency and energy conversions**	After • Teaching efficiency and energy conversion	• Energy conversions • Efficiency • Laws of thermodynamics	Describe any energy conversions that occur in the technology (or as a result of using the technology) What is the efficiency of your technology? Are there ways to improve the efficiency? Remember the laws of thermodynamics?
13	**Present**	End of unit – before exam	• all	Students present their posters to the class and answer questions. Presentations can be short and should not be graded. If no students ask questions, teacher does.

Student Handout for Physics Project:

Technology in Science

To help develop a sense of scientific literacy, you will develop an understanding of the nature of science and technology, explore the relationship between science and technology, and the social and environmental contexts of science and technology.

Technology is concerned with solving practical problems that arise from human needs. Historically, the development of technology has been strongly linked to the development of science, with each making contributions to the other. While there are important relationships and interdependencies, there are also important differences. Where the focus of science is on the development and verification of knowledge, in technology the focus is on the development of solutions, involving devices and systems that meet a given need within the constraints of the problem. The test of science knowledge is that it helps us explain, interpret and predict; the test of technology is that it works—it enables us to achieve a given purpose.

You will choose a technology you are interested in and help the rest of us understand it.

How and why do technologies develop over time?

PERFORMANCE TASK

You will analyze a technology and explain its relevance to the class in a short presentation.

Your presentation must meet the following criteria:

- **Historical Development:** You will create an illustrated timeline that describes your chosen technology which includes significant changes and improvements from its inception to current day
- **Analysis of Advancement:** You must analyze the changes that the technology has undergone over time and explain why those changes were made.
- **Connection to Curriculum:** As we progress through the study of physics, you will identify how the curriculum outcomes are applicable to your technology.

Your task is to create a presentation that insightfully educates your audience on the importance and impact of your chosen technology on humans over time, and enable us to realize how what we are learning in class is relevant to this technology.

PLANNING PAGE.

STEP ONE: Select a technology

Brainstorm a list of possible technologies:

Narrowing your choice:

Which of these technologies do you believe involves the conversion of energy from one form to another?

Which of these technologies do you believe is useful to you?

When you are selecting your technology, you ought to consider the following questions:

- Am I interested in this?
- Do I want to know more about it?
- Do I believe this technology will endure into the future?
- Does the design and function of this technology involve potential and kinetic energy and energy conversions?
- What are the impacts of this technology on the environment?
- What would the world be like without it?

STEP TWO: Research development timeline

- **Illustrate Historical Context:** Create an illustrated timeline that describes your chosen technology from its inception to current day which includes significant changes and improvements.
    - Put your timeline on poster paper. Leave room to add more information later!

STEP THREE: Analysis of Advancement

- **Explain why changes were made:** You must describe the reasons for changes. They could be due to societal need, other technological developments, or scientific discoveries, for example.
    - Add this information to your poster

STEP FOUR: Connections to Curriculum

- **Identify the concepts we are learning in class within the use of or production of your technology:** think about how the following may apply to your technology:
    - measurement
    - thermal energy transfer
    - energy conservation
    - forces within structures
    - transmission of force and motion – work
    - forms of energy
        - kinetic
        - potential
    - energy transformations

STEP FIVE: Put it all together!

Create an engaging, convincing and clear presentation to be displayed at a class “Project Fair”.

ASSESSMENT:

Your presentations will be assessed according to the following rubrics:

PERFORMANCE TASK:

	4 **Excellent**	3 **Proficient**	2 **Adequate**	1 **Limited**	**Insufficient / Blank**
Describe a technology developing over time	Demonstrates a thorough and insightful analysis of the chosen technology and comprehensively explains historical and/or contemporary significance	Demonstrates a clear and insightful analysis of the chosen technology and satisfactorily explains historical and/or contemporary significance	Demonstrates some analysis of the chosen technology and somewhat explains historical and/or contemporary significance	Demonstrates little, or no analysis of the chosen technology with an unclear explanation of historical and/or contemporary significance	No score is awarded because there is insufficient evidence of student performance based on the requirements of the assessment task.
Identify reasons for changes to technology	The reasons for change are comprehensively expressed.	The reasons for change are adequately expressed.	The reasons for change are superficial and lack development.	The reasons for change are disjointed, inaccurate, or vague.	
Communicate relevant curriculum outcomes related to technology	Communicates curriculum concepts and outcomes convincingly and in an interesting and engaging manner.	Communicates curriculum concepts and outcomes effectively and in an interesting manner.	Communicates curriculum concepts and outcomes in a straightforward manner.	Communicates curriculum concepts and outcomes in an unorganized and confused manner.	

Comments:

Rubric for Science and Technology

Student Name: ____________________

	Nominal **1**	**Functional** **2**	**Conceptual and Procedural** **3**	**Multidimensional** **4**
Conceptual understanding (problems and solutions)	identifies technology (no connection to problem)	identifies technology related to a particular problem	*clearly* identifies technology related to a particular historical or contemporary problem which is *well articulated*	*clearly* and *independently* identifies technology related to historical and contemporary problem as well as *makes connections within and between disciplines*
Connection to Science (scientific knowledge)	knows that science and technology exist, but shows no understanding of the relationship between them	realizes that scientific knowledge may lead to the development of new technologies, and new technologies may lead to scientific discovery	understands and explains that scientific knowledge may lead to the development of new technologies, and new technologies may lead to scientific discovery	understands and articulates historical and contemporary examples of scientific knowledge leading to the development of new technologies, and new technologies leading to scientific discovery
Technological development	demonstrates a token understanding of investigative techniques (follow the leader) – *does not* identify the theoretical basis of the investigation – *does not* define or delimit research questions or ideas to be tested – *does not* design investigations – *does not* collect evidence – *does not* analyze evidence or provide explanations	demonstrates understanding of need for investigative techniques (know what to expect, but may not be confident in self) – *may* identify the theoretical basis of the investigation – *may* define and delimit research questions or ideas to be tested – *does not* design investigations *independently* – collects evidence (may not be complete) in order to evaluate – analyzes evidence and provides explanations *with guidance*	demonstrates competence in using investigative techniques (knows what to do, will persevere) – identifies the theoretical basis of the investigation – defines and delimits research questions or ideas to be tested – designs investigations *cooperatively* – collects evidence in order to evaluate – analyzes evidence and provides explanations *based upon scientific theories and concepts*	demonstrates *independent* confidence in understanding of the technological process (knows what to do and why they are doing it) – *clearly* defines a delimits to problems to be solved, and establishes meaningful criteria to assess the technological solution – *clearly* identifies the constraints and trade-offs – develops and designs prototypes *independently* – tests and evaluates designs and prototypes on the basis of *clearly established* and *meaningful* criteria
Problem solving (prototypes, intended and unintended consequences, risks and benefits)	demonstrates a token understanding of technological problem solving – *does not* realize the importance of prototypes and testing – *does not* acknowledge that some problems are technological – *does not* consider unintended consequences – *does not* value the assessment of risks and benefits associated with technology	demonstrates acceptable understanding of technological problem solving – realizes the importance of prototypes and testing – acknowledges that some problems are technological – considers unintended consequences – values the assessment of risks and benefits associated with technology	demonstrates competent understanding of technological problem solving – values the importance of prototypes and testing – acknowledges that technological problems lend themselves to multiple solutions – critically considers intended and unintended consequences – assesses the risks and benefits associated with technology as appropriate	demonstrates sophisticated understanding of technological problem solving – *clearly explains* the importance of prototypes and testing – recognises that technological problems lend themselves to multiple solutions and applies this understanding across and between disciplines – critically considers intended and unintended consequences – assesses the risks and benefits associated with technology effectively and confidently

Resources: Science 10 Program of Studies, *Achieving Scientific Literacy: From Purposes to Practices* Rodger W. Bybee (1997)

Appendix C

Biology Project Overview for Teachers

<table>
<tr><th colspan="7">B I O L O G Y   P R O J E C T   D E S I G N :   O V E R V I E W</th></tr>
<tr><td colspan="6">Name of Project: What do Plants Do?</td><td>Duration: 3 Weeks</td></tr>
<tr><td colspan="6">Subject/Course: Scimatics</td><td>Grade Level: 10</td></tr>
<tr><td colspan="7">STS Focus: Nature of Science
Science provides an ordered way of learning about the nature of things, based on observation and evidence. Through science, we explore our environment, gather knowledge and develop ideas that help us interpret and explain what we see. Scientific activity provides a conceptual and theoretical base that is used in predicting, interpreting and explaining natural and technological phenomena. Science is driven by a combination of specific knowledge, theory, observation and experimentation. Science-based ideas are continually being tested, modified and improved as new knowledge and explanations supersede existing knowledge and explanations.</td></tr>
<tr><td colspan="7">Subject areas to be included: Biology, Chemistry, Climate, Mathematics</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="5">CCCAS
Cross Curricular Competencies, Attitudes*, and Skills**

These competencies, attitudes and skills are applicable beyond the curriculum of individual</td><td>Critical Thinking</td><td>X</td><td>Interest in Science*</td><td>X</td><td>Cultural and Global Citizenship</td><td>X</td></tr>
<tr><td>Communication**</td><td>X</td><td>Scientific Inquiry*</td><td>X</td><td>Personal Growth and Well-Being</td><td>X</td></tr>
<tr><td>Collaboration**</td><td>X</td><td>Managing Information</td><td>X</td><td>Stewardship*</td><td>X</td></tr>
<tr><td>Creativity and Innovation</td><td>X</td><td>Problem Solving</td><td></td><td>Safety*</td><td></td></tr>
<tr><td>Initiating and Planning**</td><td>X</td><td>Performing and Recording**</td><td></td><td>Analyzing and Interpreting**</td><td>X</td></tr>
<tr><td>Project Summary
(include student role, issue, problem or challenge, action taken, and purpose)</td><td colspan="6">Students critically consider the question “What do plants do?” through the creation of an infographic that depicts multiple aspects of plant functions, and an explanation of the biomes in which plants exist.</td></tr>
<tr><td>Driving Question</td><td colspan="6">What are the functions of plants in the world?</td></tr>
<tr><td>Entry Event</td><td colspan="6">Answer the question: What do plants do? In SEE-I format.</td></tr>
<tr><td>Products</td><td colspan="6">Infographic
My Plant’s Biome (Short Essay), SEE-I</td></tr>
</table>

BIOLOGY PROJECT DESIGN: page 2				
Making Products Public (include how the products will be made public and with whom students will engage during/at end of project)	Classmates, Student Body, Teachers, Other Staff – Infographics will be displayed in the hallways, so everyone will be able to see them.			
Resources Needed	On-site people, facilities: Wall space, collaborative classroom space			
	Equipment: computers, phones			
	Materials: blank paper, lined paper			
	Community Resources:			
Reflection Methods (how individual, team, and/or whole class will reflect during/at end of project)	Journal/Learning Log	X	Focus Group	X
	Whole-Class Discussion	X	Fishbowl Discussion	X
	Survey		Other:	

Notes:
Do not choose a real plant!
Cannot be an aquatics plant as aquatic biomes are not part of Biology 20

BIOLOGY PROJECT DESIGN: STUDENT LEARNING GUIDE

Project: What do Plants Do?

Driving Question: What are the functions of plants in the world?

Framework for Developing NOS: Teachers need to emphasize that we would not be here without plants. Point out that technologies have been developed so that we can better understand how plants have an effect on our existence.

Concepts (focus on how scientific knowledge is developed)	**Skills** (focus on scientific inquiry)	**Final Products** (where evidence of learning will be)	**CCCASs** Which CCCASs are fostered? - Possible learning experiences
the goal of science is knowledge about the natural world (NS1)	- identify, define and delimit questions to investigate (IP–NS1)	Essay	Critical Thinking - SEE-I
	- research, integrate and synthesize information from various print and electronic sources regarding a scientific question (PR–NS1)	Infographic Essay SEE-I	Manage Info - vary resources (notes, videos, internet research)
	- apply appropriate terminology, classification systems and nomenclature used in the sciences (AI–NS1)	Infographic	Communicating acquired knowledge - organizing information throughout the unit of study
	- work collaboratively to develop and carry out investigations (CT–NS1)	Interviews and observations	Collaboration - discuss and compare work with others
scientific knowledge and theories develop through hypotheses, the collection of evidence, investigation and the ability to provide explanations (NS2)	- interpret patterns and trends in data and predict the value of a variable by interpolating or extrapolating from graphical data or from a line of best fit (AI–NS2)	Biomes essay	Analyzing and interpreting
	- select and use appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate findings and conclusions (CT–NS2)	Infographic	Communication
scientific knowledge results from peer review and replication of the research of others (NS3)	- evaluate individual and group processes used in planning and carrying out investigative tasks (CT–NS3)	SEE-I Biome Essay	Critical thinking, managing information, analyzing and interpreting, communication
scientific knowledge is subject to change as new evidence becomes apparent and as laws and theories are tested and subsequently revised, reinforced or rejected (NS4)	- compile and organize findings and data by hand or computer, using appropriate formats such as diagrams, flowcharts, tables and graphs (PR–NS4)	Infographic SEE-I	Communication

scientific paradigms are conceptual inventions that help organize, interpret and explain findings (NS6) – Concepts, models and theories are often used in interpreting and explaining observations and in predicting future observations (NS6a) – Conventions of mathematics, nomenclature and notation provide a basis for organizing and communicating scientific theory, relationships and concepts; e.g., chemical symbols (NS6b) – Scientific language is precise, and specific terms may be used in each field of study (NS6c)	- state a conclusion, based on data obtained from investigations, and explain how evidence gathered supports or refutes a hypothesis, prediction or theory (AI–NS6)	Biomes essay	Analyzing and interpreting, communication

BIOLOGY UNIT PROJECT: DELIVERY GUIDE

Project: What do Plants Do?

Unit: Biology/Global Energy Movement

Driving Question: What is the purpose of plants in the world?

Teacher Focus: You are going to inspire students to consider the importance of plant life for humanity's existence.
Talk about how plants are interesting to study, but also why we should appreciate them.
Have your students thank a plant for making their lives possible.
I hope that your passion about plants will instill an insatiable curiosity in one of your students to continue to study science in some way.

Important: This project is not a stand-alone learning activity or assessment tool. It is built upon for the duration of instruction of units C (Cycling of Matter in Living Systems) and D (Energy Flow in Global Systems) from the Science 10 Program of Studies.

	Learning Activities	Timing	Content Knowledge	Project Work
1	**Initial SEE-I:** Have students **answer** the question "What do plants do?" using the SEE-I method **S**tate **E**laborate **E**xemplify **I**llustrate	After teaching • Microscopy and the emergence of cell theory • Cellular structures and functions	None so far!	First critical reflection on the function of plants
2	**Start Infographic:** **Draw** a plant (any plant) in the center of a blank paper. Must have roots, stem, and leaves (Best if not a real plant)	Just before • Using a microscope to look at plant cells	• Use of explanatory and visual models in science	Start of infographic Parts of a plant we can see with naked eye
3	**Add cell to infographic:** "blow up" a small area of a leaf and **draw** what you would see under a microscope **Add organelles to infographic** "blow up" one cell and **draw** a detailed cell including pertinent organelles and briefly **describe** their functions	After • Looking at cells under a microscope • Teaching cellular structures and functions	• Cellular structure and function, and technological applications • Use of explanatory and visual models in science	Infographic Parts of plant we need a compound light microscope to see Parts of a plant we need an electron microscope to see

4	**Add cell membrane to infographic** "blow up" an area of cell membrane and **draw** a detailed representation including pertinent structures and briefly **describe** their functions	After: • Teaching about membrane structure	• Cellular structure and function, and technological applications • Use of explanatory and visual models in science	Infographic Parts of a plant we need an electron microscope to see
5	**Add transport to infographic** **Describe** types of transport across cell membrane	After • Teaching about passive and active transport • Teaching about endo- and exocytosis	• Active and passive transport • Cellular structure and function, and technological applications • Use of explanatory and visual models in science	Infographic Theoretical explanation of the semi-permeability of cell membrane
6	**Add SA/V to infographic** **Describe** the importance of SA/V ratio in limiting cells size	After • Teaching about SA/V ratio	• Relationship between cell size and shape, and surface area to volume ratio • Cellular structure and function, and technological applications • Use of explanatory and visual models in science	Infographic Mathematical relationships
7	**Add gas exchange to infographic** **Describe** the function of stomata in gas exchange	After • Teaching about gas exchange	• Cell specialization in mechanism of gas exchange	Infographic Explaining cell specialization and function in tissues of a multicellular organism
8	**Add water transport to infographic** **Describe** the function of the xylem and the phloem in water transport	After • Teaching about water transport	• Cell specialization in transport	Infographic Explaining cell specialization and function in tissues of a multicellular organism
9	**Add plant control systems to infographic** **Describe** phototropism and gravitropism	After • Teaching about plant control systems	• Cell specialization in environmental response	Infographic Explaining cell specialization and function in tissues of a multicellular organism
10	**Biomes Essay** **Justify** in which biome your plant belongs based on physical adaptations of plants in biomes as described in class	After • Learning about biomes, solar energy, climatographs, climate and climate change	• Biological diversity, habitat diversity • Environmental monitoring, energy flow, environmental management • Climate	Essay Write and then peer review several times.

11	**Final SEE-I:** Have students **answer** the question "What do plants do?" using the SEE-I method **S**tate **E**laborate **E**xemplify **I**llustrate	End of unit	• Should be loads of content knowledge here. Will vary student to student	Critical reflection on purpose of plants

Student Handout for Biology Project:

The Nature of Science

To help you develop a sense of scientific literacy, you will develop an understanding of the nature of science and technology, explore the relationship between science and technology, and the social and environmental contexts of science and technology.

Science provides an ordered way of learning about the nature of things, based on observation and evidence. Through science, we explore our environment, gather knowledge and develop ideas that help us interpret and explain what we see. Scientific activity provides a conceptual and theoretical base that is used in predicting, interpreting and explaining natural and technological phenomena. Science is driven by a combination of specific knowledge, theory and experimentation. Science-based ideas are continually being tested, modified and improved as new knowledge and explanations supersede existing knowledge and explanations.

To focus on the nature of science, you will explain the role that plants play in biomes and how they affect climate.

What do Plants do?

PERFORMANCE TASK

You will explore the function of plants through a critical analysis of the outcomes in the curriculum. You will create an infographic that concisely illustrates your acquired knowledge about the structure of plants, and also write a short essay that communicates your understanding of the relationship of plants to the planet. Your products must meet the following criteria:

- **Critical Analysis:** You answer the question "What do plants do?" in the form of a SEE-I twice, once before we begin our study of biology, and again afterward. Your final SEE-I will demonstrate your growth in thought.
- **Infographic as communication of acquired knowledge:** You will provide a concise illustration of your knowledge about the structure of plants in the form of an infographic.
- **Connection to our world:** You will identify 2 possible biomes that your imaginary plant could exist in and describe the effects of plants like yours on climate.

Your task is to create a presentation that insightfully educates your audience on the importance and impact of plants on the world, and thus on humans, and enable us to realize how what we are learning in class is relevant to the natural world.

PLANNING PAGE!

STEP ONE: Answer the question: What do plants do?

- **Use the SEE-I format**
  - **S**tate
  - **E**laborate
  - **E**xemplify
  - **I**llustrate

STEP TWO: Plant your foundation

- **Draw a small imaginary plan**t in the center of a 11x14 paper. It must have roots, a steam, and leaves (it cannot be an aquatic plant)
  - Leave room to add A LOT more information

STEP THREE: Connections to curriculum

- **Identify the concepts we are learning in class and illustrate them on your infographic:** think about how the following may apply to your plant:
  - technology and cells
    - draw what you would see of a cell under a light microscope using proper scientific drawing
    - describe what you would see under other types of microscopes
  - plant tissues and cell specialization in leaves
    - draw a cross section of a leaf
    - draw and describe the function of each type of cell
  - the structure and function of cells
    - draw and describe the functions of organelles we have studied
  - transport systems in plants
    - draw a cross section of the cell membrane
    - describe the function of the components of the cell membrane as they relate to transport
    - illustrate and describe the types of transport we have studied
    - indicate and describe water transport in plants
    - Indicate and describe gas transport in plants
  - Control systems
    - illustrate and describe the tropisms we have studied

STEP FOUR: Give your plant a home

- **Investigate the following biomes** and determine which **two** biomes your plant would likely survive in.
    - grassland
    - desert
    - tundra
    - tiaga
    - deciduous forest
    - rain forest
- **Justify** your choice by relating it to net radiant energy, climate factors (such as temperature, moisture, sunlight and wind), as well as topography.
    - include relevant climatographs
    - include possible geographical locations
- **Communicate** your biome choices and your plant's role in relation to the climate in those biomes.
    - This will likely be in the form of a short essay, but you may choose another mode of written communication of you would like.

STEP FIVE: Answer the question again: What do plants do?

- **After you have completed the rest of this project… Use the SEE-I format**
    - **S**tate
    - **E**laborate
    - **E**xemplify
    - **I**llustrate
- Your response should show significant growth in your own thoughts as well as significant improvement in communicating what you now know.

Create an engaging, convincing and clear infographic and well written essays to be handed in to your teacher.

ASSESSMENT:

Your presentations will be assessed according to the following rubrics:

PERFORMANCE TASK:

	4 **Excellent**	3 **Proficient**	2 **Adequate**	1 **Limited**	**Insufficient / Blank**
Connection to our world	Demonstrates a thorough and insightful analysis of appropriate biomes and comprehensively justifies choice. Comprehensively describes the effects of plants on climate in an interesting manner.	Demonstrates a clear and insightful analysis of appropriate biomes and satisfactorily justifies choice. Describes satisfactorily the effects of plants on climate.	Demonstrates some analysis of appropriate biomes and somewhat justifies choice. Describes the effects of plants on climate in a way that reveals limited understanding.	Demonstrates little, or no analysis of the biomes, which may or may not be appropriate, and has an unclear justification. Does not describe the effect of plants on climate in a way that demonstrates any understanding.	No score is awarded because there is insufficient evidence of student performance based on the requirements of the assessment task.
Critical response **(include BOTH SEE-Is)**	Demonstrates a thorough and insightful analysis of the role of plants on Earth and comprehensively explains ideas.	Demonstrates a clear and insightful analysis of the role of plants on Earth and satisfactorily explains ideas.	Demonstrates some analysis of the role of plants on Earth and somewhat explains ideas	Demonstrates little, or no analysis of the role of plants on Earth with an unclear explanation of ideas	
Infographic	Communicates curriculum concepts and outcomes convincingly and in an interesting and engaging manner.	Communicates curriculum concepts and outcomes effectively and in an interesting manner.	Communicates curriculum concepts and outcomes in a straightforward manner.	Communicates curriculum concepts and outcomes in an unorganized and confused manner.	

Comments:

Rubric for NATURE OF SCIENCE **Student Name:** ____________________

Resources: Science 10 Program of Studies, *Achieving Scientific Literacy: From Purposes to Practices* Rodger W. Bybee (1997)

	Nominal **1**	**Functional** **2**	**Conceptual and Procedural** **3**	**Multidimensional** **4**
Content knowledge (terms, questions or topics)	identifies content knowledge as scientific (no connection to discipline context)	identifies content knowledge within a given discipline context	*clearly* identifies content knowledge related to discipline context	*clearly* and *independently* identifies content knowledge related to contemporary context as well as makes connections within and between disciplines
Theory (scientific theories)	knows there are scientific theories	knows that scientific theories explain scientific phenomena	understands that scientific theories explain scientific phenomena presented in science class, and that they change based on new evidence	understands scientific theories related to phenomena, and that knows these phenomena arise in areas other than the science classroom
Scientific investigation	demonstrates a token understanding of investigative techniques (follow the leader) – *does not* identify the theoretical basis of the investigation – *does not* define or delimit research questions or ideas to be tested – *does not* design investigations – *does not* collect evidence – *does not* analyze evidence or provide explanations	demonstrates understanding of need for investigative techniques (know what to expect, but may not be confident in self) – *may* identify the theoretical basis of the investigation – *may* define and delimit research questions or ideas to be tested – *does not* design investigations *independently* – collects evidence (may not be complete) in order to evaluate – analyzes evidence and provides explanations *with guidance*	demonstrates competence in using investigative techniques (knows what to do, will persevere) – identifies the theoretical basis of the investigation – defines and delimits research questions or ideas to be tested – designs investigations *cooperatively* – collects evidence in order to evaluate – analyzes evidence and provides explanations *based upon scientific theories and concepts*	demonstrates *independent* confidence in using investigative techniques (knows what to do and why they are doing it) – *clearly* identifies the theoretical basis of the investigation – *clearly* defines and delimits research questions or ideas to be tested – designs investigation *independently* – collects *appropriate* evidence in order to evaluate – analyzes evidence and provides explanations *based upon scientific theories and concepts*
Use of conventions (mathematical, nomenclature and notation)	demonstrates a token understanding of conventions – *does not* name compounds without help – *does not* use mathematical processes without help	demonstrates acceptable understanding of conventions – names given compounds without help (mostly correct) – uses given mathematical processes without help (mostly correct)	demonstrates competent understanding of conventions – names compounds whether given or independently sought – uses mathematical processes whether given or independently sought	demonstrates sophisticated understanding of conventions – always names compounds properly – always uses mathematical processes properly (when reporting)
Scientific Language (Communication)	demonstrates a token understanding of scientific language – *does not* use scientific terminology – *does not* use mathematical terminology	demonstrates acceptable understanding of scientific language – uses scientific terminology in written communication; sometimes requires prompts – uses mathematical terminology in written communication; sometimes requires prompts	demonstrates competent understanding of scientific language – uses scientific terminology in written and oral communication; may require some prompts – uses mathematical terminology in written and oral communication; may require some prompts	demonstrates sophisticated understanding of scientific language – *always* uses scientific terminology in written and oral communication – *always* uses mathematical terminology in written and oral communication

Appendix D

Chemistry Project Overview for Teachers

C H E M I S T R Y   P R O J E C T   D E S I G N :   O V E R V I E W

Name of Project: Better Living Through Chemistry?					**Duration: 12 Weeks**
Subject/Course: Scimatics					**Grade Level: 10**

STS Focus: Nature of Science and Developing a Social and Environmental Context
The history of science shows that scientific development takes place within a social context. Many examples can be used to show that cultural and intellectual traditions have influenced the focus and methodologies of science, and that science in turn has influenced the wider world of ideas. Today, research is often driven by societal and environmental needs and issues. As technological solutions have emerged from previous research, many of the new technologies have given rise to complex social and environmental issues. Increasingly, these issues are becoming part of the political agenda. The potential of science to inform and empower decision making by individuals, communities and society is central to scientific literacy in a democratic society. Science provides an ordered way of learning about the nature of things, based on observation and evidence. Through science, we explore our environment, gather knowledge and develop ideas that help us interpret and explain what we see. Scientific activity provides a conceptual and theoretical base that is used in predicting, interpreting and explaining natural and technological phenomena. Science is driven by a combination of specific knowledge, theory, observation and experimentation. Science-based ideas are continually being tested, modified and improved as new knowledge and explanations supersede existing knowledge and explanations.

Subject areas to be included: Chemistry, Environment

CCCAS Cross Curricular Competencies, Attitudes*, and Skills** These competencies, attitudes and skills are applicable beyond the curriculum of individual courses	Critical Thinking	X	Interest in Science*	X	Cultural and Global Citizenship	X
	Communication**	X	Scientific Inquiry*	X	Personal Growth and Well-Being	X
	Collaboration**	X	Managing Information	X	Stewardship*	X
	Creativity and Innovation	X	Problem Solving		Safety*	X
	Initiating and Planning**	X	Performing and Recording**		Analyzing and Interpreting**	X
Project Summary (include student role, issue, problem or challenge, action taken, and purpose/beneficiary)	Students critically consider an environmental issue and after researching provide a possible solution to the problem. They present their research and solution publicly if possible, but certainly to the class.					
Driving Question	Can environmental issues and problems be solved though chemistry?					
Entry Event	Brainstorm activity – what are some environmental problems we face right now?					
Products	Paper and Presentation					

CHEMISTRY PROJECT DESIGN: OVERVIEW				
Making Products Public (include how the products will be made public and who students will engage with during/at end of project)	Classmates, Student Body, Teachers, Other Staff, Parents – Presentations are done in a science fair format.			
Resources Needed	On-site people, facilities: Collaborative classroom space, cafeteria (don't forget to book!)			
	Equipment: computers, phones			
	Materials: student provided based on project			
	Community Resources:			
Reflection Methods (how individual, team, and/or whole class will reflect during/at end of project)	Journal/Learning Log	X	Focus Group	X
	Whole-Class Discussion	X	Fishbowl Discussion	X
	Survey		Other:	

Notes:
Don't be afraid to let them choose something totally out of the curriculum. Focus on their development scientific literacy!

CHEMISTRY PROJECT DESIGN: STUDENT LEARNING GUIDE

Project: Better Living Through Chemistry?

Driving Question: Can environmental issues and problems be solved though chemistry?

Framework for Developing SEC: Teachers need to emphasize that discoveries in chemistry have often been as a result of looking for solutions to problems. Point out that technologies have been developed so that we can better understand how chemical reactions occur, and also to control them.

Concepts (focus on how scientific knowledge is developed)	**Skills** (focus on scientific inquiry)	**Final Products** (where evidence of learning will be)	**CCCASs** Which CCCASs are fostered? - Possible learning experiences
science and technology are developed to meet societal needs and expand human capability (SEC1)	- identify questions to investigate that arise from issues related to the application of science and technology (IP–SEC1)	Paper Presentation	Critical thinking, interest in science cultural and global citizenship
	- research, integrate and synthesize information from various print and electronic sources relevant to a given question, problem or issue (PR–SEC1)	Paper Presentation	Manage information, interest in science, analyze and interpret
	- apply given criteria for evaluating evidence and assess the authority, reliability, scientific accuracy and validity of sources of information (AI–SEC1)	Paper Presentation	Scientific inquiry, collaboration, manage information, collaborate
	- work collaboratively to investigate a science-and technology-related issue (CT–SEC1)	Paper Presentation	Collaboration, personal growth
science and technology have influenced, and been influenced by, historical development and societal needs (SEC2)	- plan complex searches for information, using a wide variety of electronic and print sources (IP–SEC2)	Paper Presentation	Initiate and plan, analyzing and interpreting, scientific inquiry, manage information
	- select information and gather evidence from appropriate sources and evaluate search strategies (PR–SEC2)	Paper Presentation	Analyze and interpret,
	- apply a variety of perspectives in assessing the risks and benefits of scientific and technological developments (AI–SEC2)	Paper Presentation	Cultural and global citizenship, scientific inquiry, safety
	- communicate in a persuasive and an engaging manner, using appropriate multimedia forms, to further understand a complex science-and-technology-related issue (CT–SEC2)	Paper Presentation	Communication, creativity and innovation

science and technology have both intended and unintended consequences for humans and the environment (SEC3)	- assess and develop appropriate processes for collecting relevant data and information about science-and technology-related issues (IP–SEC3)	Paper Presentation	Critical thinking, managing information, analyzing and interpreting, communication, stewardship
	- assess potential decisions and recommend the best one, based on findings (AI–SEC3)	Paper Presentation	Critical thinking, analyze and interpret, collaborate, problem solving, communicate
	- make clear and logical arguments to defend a given decision on an issue, based on findings (CT–SEC3)	Paper Presentation	Critical thinking
society provides direction for scientific and technological development (SEC4) – Canadian society supports scientific research and technological development to facilitate a sustainable society, economy and environment (SEC4a) – Decisions regarding the application of scientific and technological development involve a variety of perspectives, including social, cultural, environmental, ethical and economic considerations (SEC4b) – Society supports scientific and technological development by recognizing accomplishments, publishing and disseminating results and providing financial support (SEC4c)	- identify new questions that arise and evaluate, from a variety of perspectives, potential implications of findings (AI–SEC4)	Paper Presentation	Critical thinking, problem solving
	- evaluate individual and group processes used in investigating an issue and in evaluating alternative decisions (CT–SEC4)	Paper Presentation	Collaboration, problem solving, critical thinking
scientific and technological activity may arise from, and give rise to, such personal and social values as accuracy, honesty, perseverance, tolerance, open-mindedness, critical-mindedness, creativity and curiosity (SEC5)		Paper Presentation	Stewardship, scientific inquiry
science and technology provide opportunities for a diversity of careers based on post-secondary studies, for the pursuit of hobbies and interests, and for lifelong learning (SEC6)		Paper Presentation	Personal growth and well-being, scientific inquiry

Student Handout for Chemistry Project:

Social and Environmental Contexts of Science and Technology

To help you develop a sense of scientific literacy, you will develop an understanding of the nature of science and technology, explore the relationship between science and technology, and the social and environmental contexts of science and technology. The history of science shows that scientific development takes place within a social context. Many examples can be used to show that cultural and intellectual traditions have influenced the focus and methodologies of science, and that science in turn has influenced the wider world of ideas. Today, research is often driven by societal and environmental needs and issues. As technological solutions have emerged from previous research, many of the new technologies have given rise to complex social and environmental issues. Increasingly, these issues are becoming part of the political agenda. The potential of science to inform and empower decision making by individuals, communities and society is a central role of scientific literacy in a democratic society. To focus on the social and environmental contexts of science and technology, you will identify and research an environmental problem that could be solved using chemistry and present your findings in a class science fair.

Better living through chemistry?

PERFORMANCE TASK

You will explore an environmental issue of your choice and create a presentation to communicate your findings to the class. Your products must meet the following criteria:

- **Research paper:** Your paper will be well researched and include well defined arguments both for and against the issue you choose. It will be a detailed analysis of the issue and include a possible solution to the problem.
- **Display:** You will provide a concise display about the issue described in your paper.
- **Oral communication:** You will present your research at a mini "science fair" where you will be asked by your teacher (and possibly others) to explain what you have learned.

Your task is to create a presentation that insightfully educates your audience on the issue and the solution you come up with. This ought to enable us to realize how what we are learning in class is relevant to the natural world.

PLANNING PAGE!

STEP ONE: Define a problem

Brainstorm a list of possible issues:

Narrowing your choice:

Which of these issues presents a problem that could potentially be solved using chemistry?

When you are selecting your topic, you ought to consider the following questions:

- Am I interested in this?
- Do I want to know more about it?
- Do I believe this problem will continue to be a problem if it is not solved?
- What are the impacts of this issue on the environment?
- Would the world be better without it?

Write your issue on the form of question that can be answered through your research:

STEP TWO: Research

- **Find as much reliable information as you can**
    - Keep track of ALL of your sources. (Plagiarism is not acceptable)
    - Determine which information you need to use to support your claims and conclusions.
    - You should also include a relevant counter-perspective in order to strengthen your argument.

STEP THREE: Write

- **Write you paper.** It should include:
    - an introduction
    - at least 2 arguments that support your position
    - one counter argument
    - a rebuttal to the counter argument (that strengthens your position)
    - a possible solution to the problem'
    - a conclusion
    - a reference list

- in-text citations must be used when paraphrasing or using direct quotes
- DO NOT PLAIGIARISE

STEP FOUR: Create your presentation

- **Include most important points of your research**
    - be concise

STEP FIVE: Present!

- **Set up your display and share what you've learned with your classmates, your teacher, and invited guests.**

Create an engaging, convincing and clear presentation that you are confident about.

ASSESSMENT:

Your presentations will be assessed according to the following rubrics:

PERFORMANCE TASK:

	4 **Excellent**	3 **Proficient**	2 **Adequate**	1 **Limited**	**Insufficient / Blank**
Paper	Problem is clearly defined. Demonstrates a thorough and insightful analysis of the issue and comprehensively explains contemporary significance. Solution provided is plausible and sufficiently defended.	Problem is clearly defined. Demonstrates a clear and insightful analysis of the issue and satisfactorily explains contemporary significance. Solution is plausible and somewhat defended.	Problem is somewhat defined. Demonstrates some analysis of the issue and somewhat explains contemporary significance. Solution is possibly plausible, but not well defended.	Problem is not defined. Demonstrates little, or no analysis of the issue, and has an unclear explanation of contemporary significance. Does not provide a plausible solution.	No score is awarded because there is insufficient evidence of student performance based on the requirements of the assessment task.
Display	Information on display is well organized and presented clearly and concisely in an aesthetically appealing manner. You want to put this up in your room because it's so great! .	Information on display is organized and presented concisely in an aesthetically appealing manner. You might keep this under your bed for a few years, but don't need to because you know it well.	Information on display is presented concisely. You'll probably never look at it again, but you know what you're talking about.	Information is not well organised, not concise, and not aesthetically appealing. This is not something you're proud of, but at least you did something.	
Presentation	Communicates arguments and solution convincingly and in an interesting and engaging manner.	Communicates arguments and solution effectively and in an interesting manner.	Communicates arguments and solution in a straightforward manner.	Communicates arguments and solution in an unorganized and confused manner.	

Comments:

Rubric for Social and Environmental Contexts

Student Name: ____________________

	Nominal **1**	**Functional** **2**	**Conceptual and Procedural** **3**	**Multidimensional** **4**
Conceptual understanding (purpose of science and technology	Sees no connection between science, technology and society beyond personal use of technology and meeting individual needs	realizes that science and technology are developed to meet societal needs and expand human capability but does not fully realize the connection between science, technology and society	identifies that science and technology are developed to meet societal needs and expand human capability and *explains* the connection between science, technology and society	*clearly* and *independently* identifies that science and technology are developed to meet societal needs and expand human capability and *meaningfully explains* the connection between science, technology and society
Connection to environment (effects on the environment)	knows that science and technology exist, but shows no understanding of impact they may have on the environment, or their ability to help us understand the environment and our place within it	realizes that science and technology are supported by society, and have influenced and been influenced by societal needs	understands that science and technology are supported by society, and have influenced and been influenced by societal needs; and realizes that they have both intended and unintended consequences on humans and the environment	Understands and confidently articulates that science and technology are supported by and support society, and have influenced and been influenced by societal needs (both historical and contemporary); and articulates that they have both intended and unintended consequences on humans and the environment
Society provides direction for scientific and technological development	demonstrates a token understanding of the relationship between STS – *does not* identify the theoretical basis of the investigation – *does not* define or delimit research questions or ideas to be tested – *does not* design investigations – *does not* collect evidence – *does not* analyze evidence or provide explanations	demonstrates understanding of need for investigative techniques (know what to expect, but may not be confident in self) – *may* identify the theoretical basis of the investigation – *may* define and delimit research questions or ideas to be tested – *does not* design investigations *independently* – collects evidence (may not be complete) in order to evaluate – analyzes evidence and provides explanations *with guidance*	demonstrates competence in using investigative techniques (knows what to do, will persevere) – identifies the theoretical basis of the investigation – defines and delimits research questions or ideas to be tested – designs investigations *cooperatively* – collects evidence in order to evaluate – analyzes evidence and provides explanations *based upon scientific theories and concepts*	demonstrates *independent* confidence in understanding of the technological process (knows what to do and why they are doing it) – *clearly* defines a delimits to problems to be solved, and establishes meaningful criteria to assess the technological solution – *clearly* identifies the constraints and trade-offs – develops and designs prototypes *independently* – tests and evaluates designs and prototypes on the basis of *clearly established* and *meaningful* criteria
Problem solving (prototypes, intended and unintended consequences, risks and benefits)	demonstrates a token understanding of technological problem solving – *does not* realize the importance of prototypes and testing – *does not* acknowledge that some problems are technological – *does not* consider unintended consequences – *does not* value the assessment of risks and benefits associated with technology	demonstrates acceptable understanding of technological problem solving – realizes the importance of prototypes and testing – acknowledges that some problems are technological – considers unintended consequences – values the assessment of risks and benefits associated with technology	demonstrates competent understanding of technological problem solving – values the importance of prototypes and testing – acknowledges that technological problems lend themselves to multiple solutions – critically considers intended and unintended consequences – assesses the risks and benefits associated with technology as appropriate	demonstrates sophisticated understanding of technological problem solving – *clearly explains* the importance of prototypes and testing – recognises that technological problems lend themselves to multiple solutions and applies this understanding across and between disciplines – critically considers intended and unintended consequences – assesses the risks and benefits associated with technology effectively and confidently

Resources: Science 10 Program of Studies, *Achieving Scientific Literacy: From Purposes to Practices* Rodger W. Bybee (1999)