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Integrating The Nature Of Science Into The International Baccalaureate Chemistry Curriculum: Lesson Plans And Resources For Educators

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INTEGRATING THE NATURE OF SCIENCE INTO THE INTERNATIONAL BACCALAUREATE CHEMISTRY CURRICULUM: LESSON PLANS AND RESOURCES FOR EDUCATORS

by

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CHAPTER ONE

Introduction

With rapid changes in science and technology, the landscape of the classroom is also changing. There is increased emphasis on the need for students to be, and for teachers to help them become, scientists or scientific thinkers. We see this in the focus on science, technology, engineering, and mathematics (STEM) programs and themed schools, the creation of innovation labs, maker spaces, genius hours, and similar programs. While students certainly need a foundation in the basics of science to understand how the universe works, the emphasis in science education has shifted to the ability to evaluate new information, be creative, think flexibly, and take risks. With this shift has come the emergence of the importance of the nature of science, which is essentially the study of the key principles of science as a way of knowing and the characteristics of scientific knowledge. Even the International Baccalaureate Diploma Program (IB DP), a rigorous and content-heavy course of student for high school students, has reorganized its chemistry syllabus around the nature of science. The purpose of this is to prepare students to apply critical thinking skills and the scientific process to new and novel concepts in chemistry. Explicitly teaching the nature of science allows students and teachers to achieve the goals of a 21st century science education, and it is critical that teachers have the resources to engage in these topics with their students.

Question

The International Baccalaureate (IB) chemistry syllabus lists forty-four standards in the nature of science and maps them onto each content topic and subtopic in the syllabus (International Baccalaureate Organization, 2014), highlighting the importance the organization places on the integration of the nature of science into the curriculum. However, the IB does not include resources for how these topics can be addressed. This raises the question: how can explicit instruction in the nature of science best be delivered and integrated with each topic the International Baccalaureate chemistry syllabus?

Background

Before discussing the specifics of writing the nature of science curriculum for the IB chemistry syllabus, some general background exploration must be undertaken. The IB must be explained in order to give context to the question. Additionally, the nature of science must also be defined and its importance in the curriculum justified.

The International Baccalaureate Organization. The IB is an internationally recognized program of study for high school students. The program of study requires students to be well-rounded academically. Students must complete a hexagon of requirements: two languages, one social science, one natural science, one math, and one arts requirement. Students can substitute the arts requirement for an additional language, social science, or natural science class. Students must take at least three and no more than four of these classes at the higher level (HL) and the rest at standard level (SL). To obtain the IB diploma, students also participate in core components, which include an Extended Essay (EE) in one of their subject areas, which is an in-depth independent research project, the class Theory of Knowledge (ToK), which examines how we know what we know, and Community Activity and Service (CAS), which requires students to participate in the school and the outside community outside of class.

The program of study takes two years and is highly rigorous and demanding for high school students. HL classes require 240 hours of class time, and SL classes require

150 hours of class time. With the addition of core requirements, the full IB diploma becomes an immersive experience. The IB also intends to be interdisciplinary. The IB chemistry course requires that ToK, international-mindedness, and the nature of science be integrated into the content topics. For example, the syllabus for Topic 3.1 (see Appendix A) about the periodic table delineates how the interdisciplinary nature of the course can be approached.

In the syllabus, the essential idea is given first. In this case, the essential idea is that "the arrangement of elements in the periodic table help to predict their electron configuration." The nature of science standard also has a prominent place in the syllabus, again conveying its importance in the IB. This is nature of science standard 1.9, which refers to its place on the list of 44 nature of science standards that the IB lists in all its science syllabi.

> The NOS [Nature of Science] statement(s) above every subtopic outline how one or more of the NOS themes can be exemplified through the understandings, applications and skills in that subtopic. These are not a repeat of the NOS statements found below but an elaboration of them in a specific context. (International Baccalaureate Organization, 2014, p. 15)

This statement is intended to help guide and shape the IB curriculum. In the left-hand column of the syllabus, the understandings, applications and skills, and guidance are listed. These are the content specific standards and benchmarks for this topic. In the right-hand column, the links to international-mindedness and ToK are listed, as well as utilization and links to other places in the syllabus. The aims refer to the overarching goals of the IB science program. The syllabus here is showing how specific content in Topic 3.1 can be used to address specific aims with students.

The aims of the IB science program also highlight the nature of science. The IB Chemistry Guide states:

> The aims enable students, through the overarching theme of the Nature of science, to:
>
> 1. appreciate scientific study and creativity within a global context through stimulating and challenging opportunities
> 2. acquire a body of knowledge, methods and techniques that characterize science and technology
> 3. apply and use a body of knowledge, methods and techniques that characterize science and technology
> 4. develop an ability to analyze, evaluate and synthesize scientific information
> 5. develop a critical awareness of the need for, and the value of, effective collaboration and communication during scientific activities
> 6. develop experimental and investigative scientific skills including the use of current technologies
> 7. develop and apply 21st century communication skills in the study of science
> 8. become critically aware, as global citizens, of the ethical implications of using science and technology
> 9. develop an appreciation of the possibilities and limitations of science and technology

> 10. develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge. (International Baccalaureate Organization, 2014, p. 27)

It is therefore crucial that the nature of science be incorporated into the teaching of chemistry in the IB, as the course is built around an understanding of the nature of science. A deeper understanding of the nature of science can also improve IB scores.

The IB chemistry course is assessed in the following way. There are three written exam papers, and an internal assessment (IA). Paper 1 is multiple choice. For SL students, this takes 45 minutes and is worth 20% of their IB grade. For HL students, this take 60 minutes and is also worth 20% of their IB grade. Paper 2 is short answer, and many of the questions deal with assumptions made in experiments and explanations for unusual findings. For SL students, this takes 75 minutes and is worth 40% of their IB grade. For HL students, this takes 135 minutes and is worth 36% of their IB grade. Paper 3 is also short answer. Section A addresses the interpretation of data and experimental findings. Section B addresses an additional topic (the option), students have their choice of energy, biochemistry, materials, or medicinal chemistry. For SL students, this takes 60 minutes and is worth 20% of their IB grade. For HL students, this takes 75 minutes and is worth 24% of their IB grade. The IA is done in class. The IB allocates 10 hours of instructional time for this task and it is worth 20% of the IB grade for both SL and HL students. Given the value placed on experimentation and interpretation of data, the nature of science is very valuable for students sitting the IB exam. While the temptation may be to focus on the content specific standards, the role that the nature of science can play in IB success should not be underestimated. It is not enough for students to simply participate in the required practicals in the IB chemistry course; the nature of science must be explicitly taught to see the benefits.

The nature of science. Science has not always been my passion. As a high school student, I enjoyed my language arts and social studies classes much more. I saw science as an application of math, and neither subject came easily to me. Perhaps because I am female, this did not particularly concern me or my teachers. Now, I teach IB chemistry and math. I graduated from Smith College with high honors in chemistry, motivated to pursue my teaching license and share my joy of science and chemistry with other people.

When I think of the paradigm shift I underwent my freshman year of college, it is important to note that I attended a women's college. While this certainly played a role in my science education, for me it was not the critical piece of my transformation. CHM 222: Introduction to Organic Chemistry was the first time I understood what science really was. And although it helped that my professor believed so strongly in the ability of women to succeed in chemistry that he had dedicated his professional life to the cause, it was ultimately his insistence that organic synthesis was a creative process that awakened my passion for science.

One of the tenets of the nature of science is that science is a creative, imaginative process (University of Waikato, 2011) and being taught explicitly about the nature of science was what allowed me to participate in the culture of science for the first time. I saw science as interesting and understandable, as well as something human. Learning about the nature of science sharpened my critical thinking skills, allowing me to "think like a scientist" – a skill I had previously thought of as nebulous and out of reach. The ability to evaluate, critique, and respond to data as a scientist not only furthered my understanding of science content, but turned me into a lifelong learner of science. The nature of science must be explicitly taught, so that students of chemistry are also students of science, and can locate their knowledge in the rapidly changing world.

What is the nature of science? Science educator and researcher Derek Hodson (2009) writes about science as its own culture. Just as professional educators have a language and culture that they use in their world, so do scientists. Science teachers are like anthropologists, and must bring their students to an understanding of the unique language, customs, practices, attitudes, and values of the scientific community (Hodson, 2009). This includes not just what scientists know, but also how it is known.

Researchers William McComas and Joanne Olson (1998) analyzed science curricula from around the world and identified fourteen statements about the nature of science:

- Science is an attempt to explain natural phenomena.
- People from all cultures contribute to science.
- Scientific knowledge, while durable, has a tentative character.
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments and skepticism.
- There is no one way to do science – therefore, there is no universal step-by-step scientific method
- New knowledge must be reported clearly and openly.
- Scientists require accurate record-keeping, peer review and reproducibility.
- Observations are theory laden.
- Scientists are creative.

- Over the centuries, science builds in both an evolutionary and a revolutionary way.
- Science is part of social and cultural traditions.
- Science and technology impact each other.
- Scientific ideas are affected by the social and historical setting.
- Laws and theories serve different roles in science – therefore, students should note that theories do not become laws even with additional evidence.

The IB syllabus distills these fourteen topics to five main topics, each with multiple subtopics for a total of 44 standards in the nature of science. These are the main nature of science standards published by the IB (2014, February).

1. What is science and what is the scientific endeavor?
2. The understanding of science
3. The objectivity of science
4. The human face of science
5. Scientific literacy and the public understanding of science

There are between six and thirteen subtopics for each of these five standards listed in the syllabus. The fourteen topics identified by McComas and Olson are generally expanded on in the IB nature of science subtopics. These nature of science standards are then assigned to IB topics, and elaborated on to connect them directly to the standard. Figure 1 shows an example of one of these specified nature of science statements. It is these elaborated statements that I will use to develop curriculum for each of the topics in the IB chemistry syllabus.

Why teach the nature of science? The nature of science should be taught because the curriculum requires it and the research supports it. However, many of the curricular materials supplied to science teachers portray the nature and process of science inaccurately or implicitly. Students also received incorrect messages about science from the media and other sources.

> Science is often misrepresented in the media, and classroom teaching can overemphasize what we know rather than how we know it. Consequently, many students see science as a boring enterprise – the tedious accumulation of facts about the world, the following of a 'scientific method' and totally lacking any imagination or creativity. (University of Waikato, 2011)

Classroom materials may also depict science as a linear process, discuss the achievements of single scientists instead of highlighting the collaborative nature of science, overemphasis cases where knowledge developed quickly instead of slowly over time, or discuss only experiments that seemed to change the entire field all at once (Understanding Science Team, para. 3). Research in the teaching of the nature and process of science suggests that in order to overcome these incorrect messages about science, students need to be explicitly instructed in the nature of science. Simply doing labs or other inquiry based activities where teachers think students are experiencing the nature of science is insufficient (Understanding Science Team, para. 1).

If students have an understanding of the nature of science, they can connect science to the real world. They develop the ability to evaluate information for themselves by deciding what scientific knowledge is relevant, how reliable that knowledge is, how that knowledge was generated, the limits of that knowledge, and how much confidence they have in that knowledge (University of Waikato, 2011). These are skills that will serve students well beyond their formal science education, as the world around them changes and science and technology come to play a larger role in all of our daily lives. Our society needs people who can think for themselves and evaluate new information and reach their own conclusions about scientific and socio-scientific questions. This will allow students to participate in the decision-making process of an active democracy that will need to consider more and more questions at the intersection of science and society.

Chapter Summary

Given the importance of the nature of science in science education, the question *how can explicit instruction in the nature of science best be delivered and integrated with each topic in the International Baccalaureate chemistry syllabus* is relevant and worth of investigation. The IB structures the chemistry syllabus around the nature of science, and the nature of science is the “overarching theme” of the IB science program. Not only can understanding the nature of science bring higher IB scores, it is also important in its own right. The nature of science is so emphasized in the IB syllabus because it is crucial for teaching students to think critically about new information and evaluate novel concepts in science. In the 21st century, this is an important skill for students to develop.

The second chapter will explore the relevant literature on curriculum development. The relevant literature includes information on how the brain learns, how the nature of science is best taught, common misconceptions about teaching and learning in the nature of science, and a lesson plan strategy that incorporates what is known about how people learn.

CHAPTER TWO

Literature Review

In order to address the question *how can explicit instruction in the nature of science best be delivered and integrated with each topic in the International Baccalaureate chemistry syllabus*, it is necessary to first discuss the social brain, what is known about how to best teach the nature of science, common misconceptions about the teaching and learning of the nature of science, and how these topics can be applied to writing lesson plans about the nature of science for IB students. These topics will inform the method for developing the lesson plans to integrate the nature of science in the IB chemistry syllabus.

In discussing the social brain, it is important to note that the human brain was not designed well for rational thinking, but rather for navigating social situations. By building on what the brain is good at, teachers can promote critical thinking skills in their students. This promotes the practice of setting clear goals for students, and the importance of activating prior knowledge when learning new information.

Next, the current literature on how to best teach the nature of science – including common misconceptions about teaching and learning in the discipline – will be discussed. The nature of science is best taught explicitly, and simply participating in inquiry labs is insufficient for understanding the nature of science. These lessons are best taught in context with science concepts, so that students can understand that the nature of science impacts real science. This means that teaching the nature of science does not need to be very time consuming, and even a small amount of instruction in this area can make a big difference for learners. Additionally, teachers may feel uncomfortable initially taking on a new topic to teach. As will any new concept, the more times it is taught the more comfortable teachers will be, and this resource provides support for that first attempt. Students are eager to learn this important information about the nature of science, and high school students are ready to work through many of the most advanced themes in the nature of science.

Finally, what is known about the brain and the teaching of the nature of science will be applied to a theory of writing lesson plans called GANAG. This theory emphasizes the need for clear goals, prior knowledge, and assessment. This section will also discuss the need for academic language goals for each lesson, and strategies for teaching language in the science classroom. The treatment of these three topics will allow for a comprehensive treatment of the research question and the development of lesson plans that are informed by how the brain works and how to best teach the nature of science.

The Social Brain

Most high school students range in age from 14 -18 years old. Students in IB chemistry are juniors and seniors; these are the last two years of schooling before university in the American system. Students typically range in age from 16 -18 years old. The brain is inherently social, and the high school brain is no exception. High school students are consciously trying to solidify their identities. Instruction for this age should promote formal operations thinking (Woolfolk, 2015, p. 51), as well as provide opportunities for students to connect with other people and explore what matters to them. With appropriate scaffolding, students at this age can develop sophisticated understandings of the nature of science. However, the human brain is not well designed for learning academic disciplines.

Learning is hard. The research of Dr. Willingham noted that "the mind is not designed for thinking" (as cite in Hattie & Yates, 2014, p. 5). Teachers want learning to be fun, and many students expect it to be as well. However, thinking requires a lot of effort, and human beings are resistant to squandering resources whenever effort is involved. This does not mean that students are lazy, but that all humans are careful when it comes to allocating personal energies. "To ask someone to invest effort is never a simple request. It involves a cost that they must consider in relation to other demands being placed upon the mind at that time" (Hattie & Yates, 2014, p. 5). And there are other motives to avoid thinking as well, such as the uncertainty of the results and the desire to avoid failure. While the brain may not best be equipped for thinking, the brain is a powerful tool for other kinds of tasks. These tasks include:

> (a) the bipedal gait and balancing the moving body over undulating terrain, (b) using visual information to make complex assessments and judgements involving time, distance, and space, (c) developing a repetitive vocabulary of about a quarter of a million words, (d) instantly being able to name between 20,000 to 30,000 common objects, (e) being able to recognize and attach names to several thousand individual faces, (f) being able to use social cues to accurately assess the mental states of others, along with (g) being able to hold a conversation taking into account the other person's orientations, timings, dispositions, and intentions. (Hattie & Yates, 2014, p. 7)

Components (e), (f), and (g) make up the social brain hypothesis, which holds that human have evolved large brains that enable us firstly to establish and maintain crucial social relationships. The general human condition is to amass the majority of our knowledge through direct social influence processes which are not highly demanding of our thinking capacities.

Teachers are confronted with roomfuls of students whose minds are designed for saving themselves from needing to think (Hattie & Yates, 2014, p. 9). Although humans are curious creatures, humans are most likely to be interested in areas in which they already have some prior knowledge and they have confidence in their ability to learn, as well as see a clear link between the effort expenditure and likely success (Hattie & Yates, 2014, p. 8). These findings inform the lesson plans that will be used to answer the research question: the lessons should make the goal clear so that students can easily see the amount of effort needed for success and that success is possible, as well as rely on prior knowledge to create interest in the topic. In order to answer the question about how to best integrate the nature of science in the IB chemistry curriculum, these ideas will impact the way the nature of science is taught, as well as the general theory of how to develop lesson plans.

How to Teach the Nature of Science

What is known about the social brain informs the way nature of science education can best be delivered at the IB level. Research shows that the best teaching on the nature of science is explicit, contextualized, and provides opportunities for students to reflect on their learning as it relates to the nature of science. This includes findings that conducting inquiry-based labs and other activities alone is insufficient for teaching the nature of science. Upon discovering the importance of the nature of science in the chemistry curriculum, some teachers may feel uneasy. Not only is this a new concept to teach, but it could take up valuable time needed for “real” content standards. Students may not even be that interested in the nature of science, or able to really tackle some of the deep philosophical issues raised. This section will address these misconceptions as well. The first of these subtopics, that the nature of science must be explicitly taught, informs the others.

Explicit teaching. In a 2004 study by Schwartz, Lederman, and Crawford, results showed that scientific inquiry in the K-12 classroom should incorporate reflective activities and explicit discussions that relate inquiry labs and other activities directly to the nature and processes of science. The study was conducted on preservice science teachers, with the aim of providing them with the context necessary to teach the nature of science in their own classrooms. During their participation in a 10-week research project, the participants were asked to write about how their work directly related to the nature of science. Eighty-five percent of the participants improved their understanding of the nature of science by participating in these reflective activities. The 15% who did not improve focused on the content of their research in their reflections rather than connecting what they had done to the nature of science. This active reflection step in which students have the opportunity to make explicit connections to the nature of science is critical in order to improve students’ understanding of science.

It is important to note that the nature of science must be explicitly taught in order to be effective, as inquiry is so stressed in the education of science teachers. As this study shows, it is not just participation in science that elicits deep learning about the nature of science. An inquiry approach without explicitly drawing connections to the nature of science is insufficient.

Inquiry and incorporation. Nearly all texts in science education center inquiry and inquiry-based investigations as best practice in science education. This gives students the opportunity to construct their own knowledge, as well as practice skills central to the nature and processes of science. However, inquiry alone is insufficient to teach the nature of science. A 2002 study by Khishfe and Abd-El-Khalick researched two sixth grade classes in Lebanon. Both classes began with generally the same low level of understanding about the nature of science and participated in the same inquiry-oriented curriculum. One group also participated in a discussion that explicitly focused on how the nature of science had been demonstrated in the lesson. The other group participated in a discussion about only the science content and skills used in the lesson. Discussing the nature of science explicitly substantially improved the students' understandings of the key elements of the nature of science, which the study defined as: the tentative, empirical, and creative nature of scientific knowledge as well as the difference between observation and inference. Even so, only 24% of the students in that group were able to consistently and accurately describe the nature of science.

This study show the importance of more than just inquiry in science education. Students need to reflect on the nature of science explicitly in order to understand it. Simply participating in science and experiencing the nature of science is not enough for students to realize the nature of science. It must be explicitly taught. The study also concludes that instruction should be incorporated over a period of time in order to reach the most students. Further research supports the theory that the nature of science is best taught over time rather than as a single unit at the beginning of the year (Understanding Science Team, n.d.). Students need multiple opportunities to revisit concepts in different contexts. Context is crucial for understanding the nature of science, and by teaching the nature of science throughout the school year instead of as a standalone unit the nature of science can be contextualized in science content.

Contextualized lessons. In a study conducted in 2006 by Clough, the author treats the concept of the nature of science the way content specific concepts are treated. Students enter the science classroom with all kinds of misconceptions about scientific concepts, and they do the same with the nature of science. Portrayals of science in media (and perhaps previous science classes) can lead students to have deep seeded and inaccurate beliefs about science. This means that students may distort new learning about science to fit their existing mental models if the instruction is not explicit and does not provide opportunities for reflection. The author also notes that highly contextualized activities make it more difficult for students to discount nature of science teaching as only applying to “school science” and not to science at large. However, the study also concludes that there is a continuum from decontextualized to highly contextualized, and that less contextualized activities also have a place in the curriculum, and as they provide opportunities to be explicit and emphasize key concepts. The best approach, therefore, incorporates instruction from all along the continuum and draws students’ attention to the connections between the different positions on the continuum.

Even with this information about how to best teach the nature of science, teachers may have doubts about how this will work in their classrooms and with their students. However, by placing the nature of science lessons in context with science content, teaching the nature of science becomes easier and less time consuming. Additionally, students are ready to have interesting conversations about the nature of science.

Misconceptions about teaching the nature of science. One common misconception about the nature of science is that an instructor cannot teach the nature of science unless they know everything about the topics. However, even addressing the nature of science in small steps over time can be very effective and lead to more sophisticated teaching about it over time and with deliberate effort. Just like any new concept or lesson a teacher tries, teaching the nature of science becomes easier and better with time (Understanding Science Team, n.d.). Additionally, this project will provide many resources to aid teachers who have not taught the nature of science before. Starting something new can be the most difficult part of the process, and this project will assist teachers with beginning their own practice of teaching the nature of science.

Another misconception is that teaching the nature of science is an add-on to the curriculum, and that there is not time to address it. The IB allocates a certain number of hours per subtopic, and it can be hard to imagine spending any of that time on the nature of science. However, the nature of science is critical for learning science concepts. Students use their conceptions about the nature of science to make decisions about whether or not to accept scientific ideas, such as evolution and climate change, as well as whether or not to continue to study science and many other important decisions (Understanding Science Team, n.d.). This is very important knowledge for students to gain. In terms of the IB specifically, knowledge about the nature of science can be applied to help students answer questions about experiments and assumptions made, as well as interpret unfamiliar problems. This is a skill that will serve students well beyond just the IB exam, and it is the goal of every teacher to teach beyond the test and impact their students' ways of thinking.

Additionally, because teaching about the nature of science is fully integrated with the content standards, it does not need to take up many of the mere minutes given to teach subtopics in the IB syllabus. Science teachers are always conveying knowledge about what science is, and the key is to take opportunities to strengthen these methods, by being explicit about the nature of science and giving students time to reflect (Understanding Science Team). This is not to say that the curriculum provided is sufficient to teach the nature of science. In multiple studies, curriculum materials have been shown to inaccurately or implicitly portray the nature of science. It is unlikely that teachers will be able to rely upon the curriculum materials provided alone (Understanding Science Team). These materials can still be useful in the classroom, as students can use their nature of science knowledge to analyze inaccurate portrayals of science and learn how to stop and correct these types of misconceptions. Students generally enjoy this type of work.

Misconceptions about learning the nature of science. Teachers may also have misconceptions about students' desire or aptitude for learning the nature of science. People tend to enjoy learning about the nature of science and what scientists really do. When students begin to learn about the nature of science, they typically want more instruction in this area. If it seems that students are not interested in the nature of science, emphasizing the human side of science can help. Research has shown that many students opt out of science majors because they see science as removed from humans (Understanding Science Team, n.d.). Understanding who scientists really are can help create interest in science. This includes information like the race, gender, religion, and cultural background of scientists. Seeing someone who looks like them and shares their values who is a scientist can build critical STEM identity and helps students stay in STEM fields.

Additionally, students are able to understand important concepts in the nature of science. Research has shown that students as young as pre-kindergarten are able to understand key concepts. However, some topics are more appropriate for certain grade levels than others. For students in grades 11-12, almost all topics in the nature of science can be discussed with students. The few standards that are best tackled at the college age are:

> (1) “all scientific tests involve making assumptions, but these assumptions can be independently tested, increasing our confidence in our test results” (2) “data interpretation can be influenced by a scientist’s assumptions, biases, and background” (3) “the scientific community motivates researchers in their investigations by providing recognition and, sometimes, a sense of competition” (4) “scientific misconduct can occur when a scientist doesn’t fairly evaluate other scientists’ work, doesn’t honestly report results, doesn’t fairly assign credit, or doesn’t work within the ethical guidelines of the community” (5) “societies may influence the course of science by directing funds towards some research topics and away from others” and (6) “authentic scientific controversy and debate within the community contribute to scientific progress by encouraging careful examination of the research.” (Understanding Science Team, n.d.)

Even so, many IB chemistry students are capable of tackling some of these college level standards. Indeed, many of the chemistry content standards covered in the HL syllabus especially require college-level work from students. Not only that, but the IB chemistry syllabus also requires links to the theory of knowledge, and understanding the nature of science can be linked across the curriculum in a way that can deepen students' understandings and allow them to work through college-level standards in the nature of science.

Given that the nature of science is best taught explicitly, throughout the year, and in context with scientific concepts, the last topic to be discussed is how to incorporate this knowledge into lesson plans. In the creation of the lesson plans provided in this project in order to best integrate the nature of science in the IB chemistry syllabus, the information about how to best teach the nature of science must be used with information about how to best teach new information in general.

How to Write Lesson Plans

The project is comprised of lessons or parts of lessons that are mapped onto the IB standards in chemistry. The IB has already provided the chemistry curriculum, the nature of science standards, and mapped those nature of science standards onto the chemistry curriculum. Therefore, this project is not a rewriting on any curriculum, but rather the creation and compilation of ideas for how to best deliver the nature of science portion of the IB chemistry curriculum. To this end, best practices in lesson plan development in science must be explored. This section will treat a lesson plan template called GANAG (Marzano, Pickering, & Pollock, 2001), and explain how it can work as a general template for incorporating what is known about how the brain learns. It will also discuss the need for building academic language in chemistry, and how language goals can be addressed in the IB chemistry classroom. Given the specificity of the definitions in the syllabus, working on academic language with students is important even for students with advanced language skills.

GANAG. GANAG is an acronym commonly used to help teachers plan lessons. There are variations on what it stands for depending on which version of GANAG is consulted and if it has been taken as a hybrid with other teaching tools. For the purposes of this project, it stands for: goal, activating prior knowledge, new knowledge, application and practice, and goal summary. This is an effective approach to introducing new concepts, and one that is based in the best understandings of how the brain learns. No matter what variation of GANAG a teacher may use their professional judgement to choose, these are each important components of the lesson to include at some point.

Goal. It is important for students to know the objective of a lesson before it begins. Many students seem to know this intuitively and often ask, "What are we doing today?" This is a valuable question for learners to ask. Knowing how to set appropriate goals for a lesson is important for lesson planning. This goal should be in language that can be shared with and understood by students.

> Students are more likely to work toward goals that are clear, specific, reasonable, moderately challenging, and attainable within a relatively short period of time. If teachers focus on student performance, high grades, and competition, they may encourage students to set performance goals. This could undermine the students' ability to learn and become task-involved and set them on a path toward alienation from learning in school and learned helplessness. (Woolfolk, 2015, pp. 441-442)

Additionally, good goals set the groundwork for good feedback. Feedback is crucial to the learning process, and in order for feedback to be effective, it should "render criteria for learning goals transparent to the learner" (Hattie & Yates, 2014, p. 70). Teachers cannot give effective feedback if learners were not aware of the learning goal during the learning. The presentation of the goal for the lesson may come first, or be delivered as part of or after the prior knowledge is activated. The presentation of the goal near the beginning of the lesson is important, but exactly when this happens is up to the discretion of the professional teacher. The goal statement and the activation of prior knowledge are both important for creating context for the new knowledge, which is crucial for the acquisition of new knowledge.

Activating prior knowledge. The activation of prior knowledge is a key step to take before introducing new content. "Our current knowledge and understanding is the filter (sometimes correctly, sometimes not) of new information – hence the importance of prior knowledge. New information that cannot be related to existing knowledge is quickly shed" (Hattie & Yates, 2014, p. 114). This means not just finding out what students already know and what misconceptions they may have brought into the classroom, but also reminding them of previous lessons. Learners need to be able to place new knowledge into context, and activating prior knowledge and making those connections explicit makes learning easier. Hattie and Yates call these "advance organizers," which serve to activate prior knowledge and tell learners how new information relates to that prior knowledge. Other lesson planning guides call this the "anticipatory set," and the concept is similar. This activation of prior knowledge can be a time for students to practice retrieving previously learned skills or concepts that will be necessary later in the lesson. This enables not only for more effective learning of the new knowledge, but also more effective practice of past skills.

New knowledge. Once prior knowledge has been activated, new information can then be taught. Most people have a natural attention span of about 15 to 20 minutes (Hattie & Yates, 2014, p. 114). This part of the lesson should either be kept short, or a break needs to be taken at about 15 minutes. New information is best delivered in a multi-model fashion.

> We are all visual learners, and we are all auditory learners, not just some of us. Laboratory studies reveal that we all learn well when the inputs we experience are multi-modal or conveyed through different media. Our brain is set up, incredibly well, as a device that integrates information from different source inputs, especially from different modalities… all students learn most effectively through linking images with words (Hattie & Yates, 2014, p. 115).

These effects become even stronger when the words and images can be linked to prior knowledge. Multiple representations of the new knowledge are important for all students to learn.

Additionally, students' minds need to be active in order to learn. Learning "occurs effectively once the mind responds to a meaningful experience through making a meaningful response. When the mind *actively* does something with the stimulus, it becomes memorable" (Hattie & Yates, 2014, p. 115). This does not mean that students always need to be conducting experiments in order to construct their own knowledge. It is possible to learn through careful observation, especially if there is no physical or motor skill involved. One of the strategies for "doing something" with the stimulus is CRIME –

chunking, rehearsal, imagery, mnemonics, and elaboration. These techniques can be used to move information into the long-term memory (Hattie & Yates, 2014, p. 123). For understanding what it means for the mind to be active, elaboration is the most important of these five to consider. "Elaboration means to process information by adding to it meaningfully. You can use the input information as a trigger for bringing other data from long-term memory into working memory consciousness. So fussing the new with the old creates a more durable and accessible memory trace" (Hattie & Yates, 2014, pp. 123-124). Here again, the role of prior knowledge in learning is emphasized in the learning of new knowledge. Spending time to practice a new skill is also important.

Application and practice. New knowledge also needs to be practiced and applied. Distributed practice is more effective than massed practice. "In most human learning situations, blocks of 15 to 30 minutes are effective in cost-benefit terms" (Hattie & Yates, 2014, p. 114). While students should be given at least 15 minutes to practice with a new concept after the introduction of new knowledge, spacing practice over time is also important. Skills in the nature of science will need to be revisited throughout the year in order for students to have enough practice time. Students may not seem to need much time to learn a new concept.

> We *appear* to learn specific small-scale behaviors, isolated bits of knowledge, or low-level objectives within only minutes. But impressions of quick learning are deceptive for many reasons. Unless material is strongly meaningful, relevant and timely, it is subject to rapid and substantial forgetting. Any new learning can be readily disrupted. To become skillful in a new area takes about 50 to 100 hours of practice. (Hattie & Yates, 2014, p. 113)

Of course, no class period is 50 hours long. This means that the material needs to be revisited throughout the year in order for students to truly become skillful in a new area. Skills practiced in this section of one lesson may need to be practiced in the prior knowledge sections of future lessons. Additionally, this furthers the case for integrating the nature of science into the curriculum, rather than teaching it as one unit at the beginning of the year, as that would be insufficient for students to become skillful. Once students have had time to practice their new skill, it is important for the students and the teacher to know if they have achieved the lesson objective.

Goal summary. The goal summary of the lesson allows students to receive feedback about the progress they are making towards the learning goal. Some type of quick formative assessment at the end of the lesson allows teachers to assess how effectively the lesson has been taught, and for students to assess their progress towards the learning goal. It is important that the feedback given on these assessments should give students the information they need to achieve their goals. “The feedback you give your students provides tools they need to be able to perceive the immediate path ahead, and so decide that it is worth the effort. Since effort is a limited commodity, it cannot be squandered on things doomed to fail, or chasms to wide to bridge” (Hattie & Yates, 2014, p. 70). This process is important for maintaining buy-in from students. While the process of learning can be tough, and not necessarily enjoyable, the feeling of achieving a planned goal does bring positive emotions (Hattie & Yates, 2014, p. 119). Letting students know that they have achieved a goal, or are on the path to achieving a goal, is important for maintaining positive feelings about the learning process.

In a 2011 study by Allchin, the author holds that the nature of (whole) science is commonly assessed with too much emphasis on declarative knowledge rather than conceptual understanding. This makes the assessments inauthentic, in that they examine student knowledge outside of the context in which that knowledge should be used. Students are capable of memorizing a list of the tenants of the nature of science, but this oversimplified and incomplete understanding of science will not serve them well in solving new and unfamiliar problems in chemistry. Allchin argues that “we should be interested in whether students can effectively analyze information about scientific and socioscientific controversies and assess the reliability of scientific claims that affect their decision making.” To do this, Allchin advocated for asking students to analyze historic and modern case studies of scientific and socioscientific controversies. Experimental questions form the IB papers 2 and 3 could also be used to serve this purpose, as well as asking students to examine case studies that the teacher creates for the purpose of assessing a particular nature of science skill. This may take more time than a traditional end of class formative assessment, but it is important to budget time for this important part of the lesson sequence.

The GANAG sequence in a valuable lesson planning tool because it incorporates the science of how the brain learns into planning an effective lesson. It is important to ensure that in this sequence, the goals are appropriate and that the instruction is multi-modal. Additionally, while topics in the nature of science may not seem to lend themselves to assessment as easily as traditional chemistry concepts, conducting an assessment of these topics is important. The GANAG strategy can be used for a content goal and an academic language goal simultaneously. It is important to include opportunities for students to use all the skills they are learning – including how to communicate about the nature of science and draw distinctions between key terminology in the nature of science and chemistry.

Academic language. In addition to the lesson sequence of GANAG, it is important to incorporate opportunities for students to build academic language skills in English. Along with a content goal, each lesson should also have an academic language goal. This will allow students to build their English language skills as well as their science language skills. There are three main theories that explain how language is acquired: language is learned through (1) imitation and habit formation, (2) an innate cognitive process, (3) a process of social interaction (Coelho, 2013, p. 141). This means that it is important for students to hear the teacher use the vocabulary they are expected to use themselves, so that they can imitate the sound of the new words. Students will also need explicit instruction in some elements of their new science language – for example, that “data” is the plural, not the singular. It is also crucial that students have many chances to practice with the new vocabulary and structures.

> Merrill Swain, another language-acquisition researcher, says that input alone is not enough; it is also necessary for learners to produce meaningful output and receive feedback that will enable them to refine their language use… Students need to be involved in small-group activities that push them to participate orally, rather than simply listen, observe, and follow directions. (Coelho, 2013, p. 147)

These are three components to keep in mind when designing lesson plans.

One specific technique that is effective for learning vocabulary in science is a word sort. This activity prompts students to discuss the meanings of the new words in relation to each other.

> Word sort typically consist of 10 to 20 terms and can be closed or open. Closed word sorting activities are performed using categories provided by the teacher… An open sort is similar, but students create a set of categories to reflect their understanding of the relationships between and among a set of words… Other word sorts may focus on word patterns or derivations. (Fisher & Frey, 2012, pp. 51-52)

Asking students to justify the categories they choose can also deepen their understanding of the vocabulary.

It can also be helpful for students who speak another language to list cognates and parts of words that are similar or the same in their other language. For example, since *mil* means “thousand” in Spanish, a Spanish-speaker could use that word part to help dissect the word “millimeter.” These connections can be shared for the benefit of all learners in the class. Most IB DP students should have a firm grasp of academic English if they are sitting exams in English. However, these strategies for building academic language are important for all levels of language acquisition and are still important tools to use in the IB classroom.

The IB requires students to use vocabulary very specifically – for example, a student who does not know the difference between an atom and an element could lose a handful of points on Paper 2. It is important that students have a chance to draw the distinction between these two terms and use them correctly. There are several terms in chemistry like this that have key differences, and that students may be required to define specifically. Giving students a chance to manipulate these terms and to practice with them in context is important to solidify their understandings.

Chapter Summary

In order to address the question *how can explicit instruction in the nature of science best be delivered and integrated with each topic in the International Baccalaureate chemistry syllabus* this chapter has discussed the social school brain, what is known about how to best teach the nature of science – and what are some common misconceptions, and how these topics can be applied to writing lesson plans about the nature of science for IB students.

Due to the highly social nature of the brain, learning is not always a pleasant experience. In order to make learning more enticing for the social brain, it is important to make sure a lesson goal is set that is worth the effort for learners. This means that the learning target needs to be clear to students from the beginning and that the introduction of the goal should be rooted in prior knowledge. This knowledge of how the brain works will also inform the use of the GANAG lesson template.

The nature of science itself is best taught in a way that is explicit, incorporated throughout the year, and with some degree of contextualization. Simply providing inquiry labs and other activities that allow students to experience science is insufficient for learning about the nature of science. These concepts need to be explicitly addressed in discussions and students need to be given time to reflect. This time needs to be spread throughout the year, so that students have a chance to revisit the material in new contexts and achieve the 50 to 100 hours needed to achieve mastery. The context of the nature of science is also important. While there is a place in the curriculum for lessons that have little context in chemistry, it is important to discuss this with students and to provide contextualized opportunities. This will make it more difficult for the social brain to dismiss this uncomfortable learning about the nature of science.

These contextualized lessons do not have to be very long to be effective. And rather than take time away from chemistry content, they are in fact key for students to understanding chemistry content fully. High school students – especially those in the IB – are ready to have in depth discussions about difficult and interesting questions in the nature of science. These types of lessons are generally enjoyed by students, who are focused on developing their own identities and are fascinated by ethical dilemmas in particular.

The lesson plan template of GANAG provides a useful acronym for including key elements of the construction of knowledge into each lesson about the nature of science. The main theory of GANAG is that prior knowledge is key to learning new knowledge, and can be used along with the goal statement to help students organize new concepts. It is also important to allow students time to practice a new skill, and to assess and give feedback on their ability to perform the new skill. This assessment of the nature of science skills should ask students to apply the nature of science to case studies in chemistry in order to best assess if their nature of science education is allowing them to approach new and novel concepts in chemistry. It is important to include academic language goals as part of the GANAG template, and to provide students with opportunities to hear and use the academic language they need to succeed in IB chemistry.

By understanding the importance of clear learning goals, prior knowledge, strategies for delivering new knowledge in the nature of science, the need for application and assessment of that application, the lesson plans for integrating the nature of science in the IB chemistry curriculum can be created. This resource will provide support for teachers new to teaching the nature of science, as they adapt the lesson plans provided to suit their own needs, as well as provide new ideas for teachers who are accustomed to teaching the nature of science.

Chapter 3 will address the description of the project. In this section, the paradigm for the project and the method for its execution will be discussed. The nature of science standards and their corresponding chemistry content standards will be addressed. Additionally, the template for the GANAG lessons will be discussed, including the use of academic language goals in the lesson plans. Finally, the timeline for the project will also be discussed.

CHAPTER THREE

Project Description

This project is a collection of lesson plans for teaching the nature of science in the IB Chemistry syllabus. A downloadable and editable lesson plan will be available for each topic, along with any resources needed to teach the lesson (handouts, manipulatives, etc.). Ideally, this will be a living document and teachers from around the world will be able to leave their ideas, comments, and questions for each other. These lesson plans are the answer to the research question *how can explicit instruction in the nature of science best be delivered and integrated with each topic in the International Baccalaureate chemistry syllabus?* This chapter will address the paradigm, method, theory, and timeline for addressing the question.

Project Paradigm

There are many resources that exist about the nature of science and about teaching the IB Chemistry syllabus. This project is a resource for teaching the nature of science specifically in IB chemistry. Even as the IB syllabus itself emphasizes the importance of teaching the nature of science, when pressed for time the instinct of many teachers is to focus on the content standards. However, given that the nature of science needs to be explicitly taught with time for reflection and that simply participating in science through inquiry or inquiry-based activities is not enough to gain an understanding of the nature of science, approaching the content standards only can lead to lower scores. In order for teachers to be able to fully incorporate the nature of science into their courses, there must be a resource that is easily accessible and flexible enough to adapt to different classrooms and teaching situations. This will allow teachers to spend less time preparing for nature of science lessons, as the bulk of the work will already be done. Teachers can then use their time to tackle the many other demands the IB and teaching in general place on their time. The main audience for this project is IB chemistry teachers all over the world, although many of these lessons could be adapted for use in an Middle Year Program (MYP) or other pre-IB chemistry class. However, the context for which the project was created was IB chemistry classrooms all over the world and in all kinds of schools. My creation of the lesson plans was of course informed by my own specific context at Academia Cotopaxi in Quito, Ecuador. In my school, most students are Ecuadorian, speak English as a second or even third language, and are preparing to attend colleges and universities around the world. In the high school, we have about 170 students, and my class sizes for IB chemistry are in the teens. Ideally, by creating a living document, the project will adapt and accommodate the diverse contexts in which IB chemistry teachers work, not all of which can be foreseen at the time of launching the project.

Method and Theory

The question will be answered by a collection of downloadable and editable lesson plans on a Google Blogger site (https://chemistrynos.blogspot.com/). There are ten lesson plans in total – one for each of the topics in the IB chemistry syllabus once Topic 6: Chemical kinetics and Topic 7: Equilibrium have been combined. The site includes an introduction that explains who I am, how to use the site, what the nature of science is, and why teaching it is important. Under the introductory post, there is one post for each of the ten lesson plans in the order in which I teach them during my two-year IB chemistry course. Each post simply contains the link to the Google doc with the lesson plan.

Collaborators can download the Google doc, and leave comments directly on the Blogger site for other educators to see.

The site will also be linked to the Programme Resource Centre of MyIB, the IB's central location for resources and applications. MyIB is the new hub for resources on how to teach the IB, and teachers can comment on the usefulness of resources posted by others. As an IB chemistry teacher, this is often my first stop when I need a resource for my class, and I'm confident that by posting it there, my site will be seen by other IB chemistry teachers who are interested in teaching the nature of science. This will allow other teachers to easily access the material either by an online search or by searching MyIB. It will also allow teachers from around the world to comment on the lesson plans that are available and leave notes for future teachers. They may have other lesson plans that fit the standard, or improvements to the lesson plans I post. Hopefully it will be a place where teachers can discuss what is working or not working in their classrooms with regards to the teaching of the nature of science and provide a space for professional reflection. These conversations will not be created as part of the capstone, but continue on after I have completed my part of the project. This method will not require IRB approval.

The nature of science strand for each content standard has been identified by the IB and will not be changed. Appendix A is a table that identifies each of the standards in the SL IB Chemistry syllabus and the corresponding nature of science standard. The project will include lesson plans to address one of these nature of science standards per content topic in some degree of context with the content standards to which they are assigned.

The lessons themselves will be based on the GANAG template, using a template (Appendix B) provided by the Twin Cities Teacher Collaborative (TC2) at Hamline University. Each section of the template, with the exception of "post-instructional reflection," will be filled in with the specifics of each lesson provided as part of the project. Along with being able to change any part of the lesson they wish, teachers can also fill in this last section with their own reflections and ideas about how the lesson went.

Timeline

The project and capstone will be completed in the fall of 2017. During the fall semester, lesson plans will be gathered and written for the project. The website will be ready for use at the end of the fall semester.

Chapter Summary

This chapter has addressed the paradigm, method, theory, and timeline for answering the question: how can explicit instruction in the nature of science best be delivered and integrated with each topic in the International Baccalaureate chemistry syllabus? Lesson plans will be created in the template (see Appendix B) provided by TC2 in order to address the nature of science standards (see Appendix A) in the SL syllabus. These lesson plans will be available for download and use by other IB chemistry teachers. The platforms where they are available will also invite discussion from teachers about teaching the nature of science. This time saving resource will allow teachers to provide important nature of science instruction. In the fourth and final chapter of this project, a reflection on the project and concluding thoughts will be given.

CHAPTER FOUR

Conclusions

In this project, the question *how can explicit instruction in the nature of science best be delivered and integrated with each topic the International Baccalaureate chemistry syllabus?* has been examined. Teaching the nature of science in the IB is important because it can raise IB scores by giving students the skills to analyze experiments and answer questions about new and novel concepts in chemistry. Beyond that, it furthers the goals of a science education by giving students opportunities to build STEM identity and become scientifically literate citizens. The IB structures the syllabus around the nature of science, but given the time constraints on an IB teacher, the barrier to teaching the nature of science can be very high. In order to lower that barrier, this project includes ten lesson plans, one for each of the topics in the SL syllabus when Topic 6 and Topic 7 are taught together. These lesson plans use an evidence-based approach in lesson planning as well as teaching the nature of science specifically in order to best address these topics. These lesson plans are posted on a Google Blogger site (https://chemistrynos.blogspot.com/), and the goal of this project is to turn these lesson plans into living documents where IB chemistry teachers from all over the world can comment and share their feedback and ideas.

Throughout the process of creating these lesson plans, I have been pushed to reflect on my own teaching and learning. Through this reflective process, I have arrived at some final conclusions about my project, which are the focus of this chapter. In chapter four, I will reflect on what I have learned in the making of my project, with focus on how it has shifted my thinking about teaching in the IB. The literature review will be revisited in order to discuss the connections between my finished project and my literature review, including locating my project in the current literature. I will also consider the implications and limitations of my project, in order to provide a framework for discussing ideas for future projects and how to communicate my project to interested parties.

Reflections

The main takeaway I have from making my project is about the way I use my time in the IB. This project came from a realization that because I was so concerned with covering the concrete material that will be on the IB exams, I was letting the nature of science, something that was very important to me, fall to the wayside. In completing this project, I have found that there are, in fact, many areas of my teaching in the IB program that I have not been very attentive to in favor of finishing the syllabus.

In making the lesson plans for my topics, I found myself consistently struggling with three main areas: academic language functions, evidence of cultural relevance, and the goal assessment. This helped me reflect on my teaching in general, and brought me back to one of the main reasons I started this project in the first place. As an IB teacher, I felt that with the time constraints on the curriculum some important pieces often get left out of the IB, such as the nature of science. Writing these lesson plans brought to my attention that academic language, relevance, and goal assessment are also key pieces that I have not been very attentive to with my IB classes. Including them in the lesson plans made me reconsider how important those pieces are for student learning at all levels. One of the challenges for students in the IB is that there is a lot of material that is covered over the course of two years, and the class moves quite quickly and at a high level. I push myself to move quickly so that I can have a significant amount of time to review material with students in the spring of their senior year before the exams. I am wondering now if I would be better served to move more slowly through the material and make sure I take the time to build academic language, make real-world connections more explicit, and allow students more chances to perform formative assessments. While this would leave me less time to review, I would probably need less time as well.

Additionally, the format of the lesson sequence encouraged me to think about what my students are doing over the course of a lesson and how much and how often that varies. For many of my IB lessons, the “student engagement” section would simply read “students take notes.” Although note taking is certainly important, I need to give my students more varied tasks, even if it is just processing time that includes other modes during my lecture.

Creating these lessons was a good chance for me to reflect on the way I teach IB chemistry in general, not just the ways in which I could teach the nature of science. Indeed, a large portion of my literature review focused on general best practices for teaching, not just for teaching the nature of science, and for me that ended up being the most important part.

Literature Review Revisited

In looking back at my literature review, I have found the contextualization of nature of science lessons and the GANAG lesson sequence to be the most useful. These two topics guided most the way in which I constructed the lesson plans.

The 2006 Clough study found that contextualized lesson about the nature of science are important for students, as this keeps them from discarding this information as separate from science. The study also indicates that there is value to decontextualized lessons as well, so that key concepts can be emphasized more explicitly. The lessons that I have created include approaches all along the continuum from decontextualized to contextualized, so as to provide different opportunities for students to examine the nature of science. There are also standards in the nature of science that are examined more than once in the lesson plans, so as to give students different kinds of context for learning about the same tenet of the nature of science. This study proved very helpful for me in giving me the freedom to create some decontextualized lessons that act as hooks into a topic or subtopic of study, and by allowing me to build nature of science ideas into existing lessons in a highly contextualized way. This variety feels more natural in the course of the syllabus, and allowed me to build on what I was already doing in my classroom.

The GANAG lesson sequence (citation) also proved very helpful. At its core, good teaching about the nature of science is just good teaching in general, and the GANAG lesson sequence reminded me of what techniques can be employed throughout the course of a lesson or mini-lesson to help students learn more deeply. Beginning the lesson plan with a clear goal that can be shared with students (Hattie & Yates, 2014, p. 70) allows students to know the context for their new knowledge. Activating prior knowledge is also helpful in creating context, especially since so many students bring misconceptions about the nature of science to the classroom. This can be a time for students recall previous lessons as well, and locate their new knowledge in what they already know. This allows students to incorporate their new knowledge more easily, making it more memorable (Hattie & Yates, 2014, p. 115). The new knowledge section also reminded me to keep dissemination of new information to 15 minutes at the maximum and to vary the mode of instruction. While students can pay attention and absorb new information for a maximum of about 15 minutes, they also need about 15 minutes of practice with a new skill in the first application and practice section (Hattie & Yates, 2014, p. 114). The skills will have to be revisited over the course of the year in order for students to solidify their understandings, and that is another reason why provided the same nature of science standards in different contexts is important for students' learning. Finally, the assessment of the goal is important so that teachers and students can receive feedback on the learning (Hattie & Yates, 2014, p. 70). Attending to these five areas when creating my lesson plans was very important in ensuring that they would include the necessary elements to maximize student learning.

However, even with this research based approach, my answer to the question posed in this paper is still limited.

Limitations and Implications

One of the limitations of my project is that, to this point, it has only been worked on by one teacher (me). This is only my third year of teaching and my second year of teaching in the IB, and I consider myself by no means to be in expert in either one of these areas. This is why it is important that the project is shared with other teachers and that it becomes a collaborative work. The lesson plans and resources I have created here are only the beginning, and by involving IB teachers from around the world to give their feedback and ideas, I believe that together we can fully answer my question: *how can explicit instruction in the nature of science best be delivered and integrated with each topic the International Baccalaureate chemistry syllabus?* I do not claim to know what the "best" way is, although I have certainly proposed some research-based suggestions in my project. The question itself also presents a limitation, as the qualifier “best” is hard to define in teaching. What may be best in my classroom with my students may not be the best in someone else’s classroom and with a different set of students. By seeking to provide some best practices that are based in research, I hope that other teachers will be able to exercise their professional judgement to answer the question in their own way in their own classrooms.

Therefore, one of the implications of my project must be that it creates collaboration between IB chemistry teachers around the world. In order to the project to truly finish, it must become a living document. This will require the communication of my project to teachers who would be interested in collaborating with me to continue this work.

I hope that my project will have a positive benefit on the teaching of IB chemistry. Instruction in the nature of science is important for deepening student learning in IB chemistry as well as developing their scientific thinking skills. While many IB teachers know this, taking the next step and actually delivering quality nature of science instruction can be difficult for a variety of reasons, mostly time related. By providing the lesson plans in an easy to use format, and by only asking teachers to give these ten lessons, some of which do not even take a whole class period, these barriers will be lowered. Even a little bit of high quality nature of science instruction can make a big difference for our students, and I hope this resource will prove the necessary access.

Future Projects and Communication

In order to communicate about my project to other IB chemistry teachers, I will post a link to the Blogger with all of my lesson plans on MyIB in the Programme Resource Centre. This will allow other IB teachers who are seeking resources on teaching the nature of science to find it. In order to further publicize the resource, Mr. Bordaguibel and I will write to *The International Educator*, a magazine widely read in the international school community, in order to share the resource with more teachers. I am also submitting a proposal to present my project at the IB Global Conference this summer. I hope that this will be a chance for IB chemistry teachers to add their ideas and feedback to my lesson plans, as well as other Group 4 teachers to collaborate on creating their own resource like this. It would be wonderful to have a resource like this for all IB science classes that teachers all over the world could use.

Chapter Summary

This chapter has evaluated conclusions reached on the question *how can explicit instruction in the nature of science best be delivered and integrated with each topic in the International Baccalaureate chemistry syllabus.* Creating the project gave me space to reflect more deeply on my own teaching of many facets of the IB chemistry syllabus, not just the nature of science. While I was able to use a research-based approach to create lesson plans on the nature of science for each topic in the syllabus, whether or not they are the “best” is not conclusive. Communication of the project and collaboration with other IB chemistry teachers will be necessary to finish the project. Receiving feedback from other educators will be key to truly answering the question, and providing the best possible resources for teaching the nature of science in the IB chemistry curriculum.

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APPENDIX A

Essential idea: The arrangement of elements in the periodic table helps to predict their electron configuration.

3.1 Periodic table	
Nature of science: Obtain evidence for scientific theories by making and testing predictions based on them—scientists organize subjects based on structure and function; the periodic table is a key example of this. Early models of the periodic table from Mendeleev, and later Moseley, allowed for the prediction of properties of elements that had not yet been discovered. (1.9)	
Understandings: • The periodic table is arranged into four blocks associated with the four sub-levels—s, p, d, and f. • The periodic table consists of groups (vertical columns) and periods (horizontal rows). • The period number (*n*) is the outer energy level that is occupied by electrons. • The number of the principal energy level and the number of the valence electrons in an atom can be deduced from its position on the periodic table. • The periodic table shows the positions of metals, non-metals and metalloids. **Applications and skills:** • Deduction of the electron configuration of an atom from the element's position on the periodic table, and vice versa. **Guidance:** • The terms alkali metals, halogens, noble gases, transition metals, lanthanoids and actinoids should be known. • The group numbering scheme from group 1 to group 18, as recommended by IUPAC, should be used.	**International-mindedness:** • The development of the periodic table took many years and involved scientists from different countries building upon the foundations of each other's work and ideas. **Theory of knowledge:** • What role did inductive and deductive reasoning play in the development of the periodic table? What role does inductive and deductive reasoning have in science in general? **Utilization:** • Other scientific subjects also use the periodic table to understand the structure and reactivity of elements as it applies to their own disciplines. Syllabus and cross-curricular links: Topic 2.2—electron configuration **Aims:** • **Aim 3**: Apply the organization of the periodic table to understand general trends in properties. • **Aim 4**: Be able to analyse data to explain the organization of the elements. • **Aim 6**: Be able to recognize physical samples or images of common elements.

Chemistry guide

Figure 1. Shows the format of the IB syllabus for the example, Topic 3.1. (International Baccalaureate Organization, 2014, p. 51)

APPENDIX B

Table 1. Showing the nature of science standards in the IB Chemistry syllabus with their corresponding chemistry content standard. The numbers show the topic and subtopic from which the standard was taken in the syllabus.

Content Standard	Nature of Science Standard
1.1 Physical and chemical properties depend on the ways in which different atoms combine.	3.1 Making quantitative measurements with replicates to ensure reliability—definite and multiple proportions.
1.2 The mole makes it possible to correlate the number of particles with the mass that can be measured.	2.3 Concepts—the concept of the mole developed from the related concept of "equivalent mass" in the early 19th century.
1.3 Mole ratios in chemical equations can be used to calculate reacting ratios by mass and gas volume.	1.8 Making careful observations and obtaining evidence for scientific theories—Avogadro's initial hypothesis.
2.1 The mass of an atom is concentrated in its minute, positively charged nucleus.	1.8 Evidence and improvements in instrumentation—alpha particles were used in the development of the nuclear model of the atom that was first proposed by Rutherford. 2.3 Paradigm shifts—the subatomic particle theory of matter represents a paradigm shift in science that occurred in the late 1800s.
2.2 The electron configuration of an atom can be deduced from its atomic number.	1.8 Developments in scientific research follow improvements in apparatus—the use of electricity and magnetism in Thomson's cathode rays. 1.9 Theories being superseded—quantum mechanics is among the most current models of the atom. 2.2 Use theories to explain natural phenomena—line spectra explained by the Bohr model of the atom.
3.1 The arrangement of elements in the periodic table helps to predict their electron configuration.	1.9 Obtain evidence for scientific theories by making and testing predictions based on them—scientists organize subjects based on structure and function; the periodic table is a key example of this. Early models of the periodic table from

	Mendeleev, and later Moseley, allowed for the prediction of properties of elements that had not yet been discovered.
3.2 Elements show trends in their physical and chemical properties across periods and down groups.	3.1 Looking for patterns—the position of an element in the periodic table allows scientists to make accurate predictions of its physical and chemical properties. This gives scientists the ability to synthesize new substances based on the expected reactivity of elements.
4.1 Ionic compounds consist of ions held together in lattice structures by ionic bonds	2.2 Use theories to explain natural phenomena—molten ionic compounds conduct electricity but solid ionic compounds do not. The solubility and melting points of ionic compounds can be used to explain observations.
4.2 Covalent compounds form by the sharing of electrons.	2.5 Looking for trends and discrepancies—compounds containing non-metals have different properties than compounds that contain non-metals and metals. 2.2 Use theories to explain natural phenomena—Lewis introduced a class of compounds which share electrons. Pauling used the idea of electronegativity to explain unequal sharing of electrons.
4.3 Lewis (electron dot) structures show the electron domains in the valence shell and are used to predict molecular shape.	1.10 Scientists use models as representations of the real world—the development of the model of molecular shape (VSEPR) to explain observable properties.
4.4 The physical properties of molecular substances result from different types of forces between their molecules.	2.2 Obtain evidence for scientific theories by making and testing predictions based on them—London (dispersion) forces and hydrogen bonding can be used to explain special interactions. For example, molecular covalent compounds can exist in the liquid and solid states. To explain this, there must be attractive forces between their particles which are significantly greater than those that could be attributed to gravity.
4.5 Metallic bonds involve a lattice of cations with delocalized electrons.	2.2 Use theories to explain natural phenomena—the properties of metals are different from covalent and ionic

	substances and this is due to the formation of non-directional bonds with a "sea" of delocalized electrons.
5.1 The enthalpy changes from chemical reactions can be calculated from their effect on the temperature of their surroundings.	2.6 Fundamental principle—conservation of energy is a fundamental principle of science. 3.1 Making careful observations—measurable energy transfers between systems and surroundings.
5.2 In chemical transformations energy can neither be created nor destroyed (the first law of thermodynamics).	2.4 Hypotheses—based on the conservation of energy and atomic theory, scientists can test the hypothesis that if the same products are formed from the same initial reactants then the energy change should be the same regardless of the number of steps.
5.3 Energy is absorbed when bonds are broken and is released when bonds are formed.	2.2 Models and theories—measured energy changes can be explained based on the model of bonds broken and bonds formed. Since these explanations are based on a model, agreement with empirical data depends on the sophistication of the model and data obtained can be used to modify theories where appropriate.
6.1 The greater the probability that molecules will collide with sufficient energy and proper orientation, the higher the rate of reaction	2.7 The principle of Occam's razor is used as a guide to developing a theory—although we cannot directly see reactions taking place at the molecular level, we can theorize based on the current atomic models. Collision theory is a good example of this principle.
7.1 Many reactions are reversible. These reactions will reach a state of equilibrium when the rates of the forward and reverse reaction are equal. The position of equilibrium can be controlled by changing the conditions.	1.8 Obtaining evidence for scientific theories—isotopic labelling and its use in defining equilibrium. 5.5 Common language across different disciplines—the term dynamic equilibrium is used in other contexts, but not necessarily with the chemistry definition in mind.
8.1 Many reactions involve the transfer of a proton from an acid to a base.	2.5 Falsification of theories—HCN altering the theory that oxygen was the element which gave a compound its acidic

	properties allowed for other acid–base theories to develop. 1.9 Theories being superseded—one early theory of acidity derived from the sensation of a sour taste, but this had been proven false. 5.5 Public understanding of science—outside of the arena of chemistry, decisions are sometimes referred to as "acid test" or "litmus test".
8.2 The characterization of an acid depends on empirical evidence such as the production of gases in reactions with metals, the colour changes of indicators or the release of heat in reactions with metal oxides and hydroxides.	1.9 Obtaining evidence for theories—observable properties of acids and bases have led to the modification of acid–base theories.
8.3 The pH scale is an artificial scale used to distinguish between acid, neutral and basic/alkaline solutions.	2.7 Occam's razor—the pH scale is an attempt to scale the relative acidity over a wide range of H+ concentrations into a very simple number.
8.4 The pH depends on the concentration of the solution. The strength of acids or bases depends on the extent to which they dissociate in aqueous solution.	1.8 Improved instrumentation—the use of advanced analytical techniques has allowed the relative strength of different acids and bases to be quantified. 3.1 Looking for trends and discrepancies—patterns and anomalies in relative strengths of acids and bases can be explained at the molecular level. 1.9 The outcomes of experiments or models may be used as further evidence for a claim—data for a particular type of reaction supports the idea that weak acids exist in equilibrium.
8.5 Increased industrialization has led to greater production of nitrogen and sulfur oxides leading to acid rain, which is damaging our environment. These problems can be reduced through collaboration with national and intergovernmental organizations.	4.8 Risks and problems—oxides of metals and non-metals can be characterized by their acid–base properties. Acid deposition is a topic that can be discussed from different perspectives. Chemistry allows us to understand and to reduce the environmental impact of human activities.

9.1 Redox (reduction–oxidation) reactions play a key role in many chemical and biochemical processes.	1.9 How evidence is used—changes in the definition of oxidation and reduction from one involving specific elements (oxygen and hydrogen), to one involving electron transfer, to one invoking oxidation numbers is a good example of the way that scientists broaden similarities to general principles.
9.2 Voltaic cells convert chemical energy to electrical energy and electrolytic cells convert electrical energy to chemical energy.	4.5 Ethical implications of research—the desire to produce energy can be driven by social needs or profit.
10.1 Organic chemistry focuses on the chemistry of compounds containing carbon.	1.4 Serendipity and scientific discoveries—PTFE and superglue. 4.5 Ethical implications—drugs, additives and pesticides can have harmful effects on both people and the environment.
10.2 Structure, bonding and chemical reactions involving functional group interconversions are key strands in organic chemistry.	3.1 Use of data—much of the progress that has been made to date in the developments and applications of scientific research can be mapped back to key organic chemical reactions involving functional group interconversions.
11.1 All measurement has a limit of precision and accuracy, and this must be taken into account when evaluating experimental results.	3.2, 3.4 Making quantitative measurements with replicates to ensure reliability—precision, accuracy, systematic, and random errors must be interpreted through replication.
11.2 Graphs are a visual representation of trends in data	2.8 The idea of correlation—can be tested in experiments whose results can be displayed graphically.
11.3 Analytical techniques can be used to determine the structure of a compound, analyse the composition of a substance or determine the purity of a compound. Spectroscopic techniques are used in the structural identification of organic and inorganic compounds.	1.8 Improvements in instrumentation—mass spectrometry, proton nuclear magnetic resonance and infrared spectroscopy have made identification and structural determination of compounds routine. 1.10 Models are developed to explain certain phenomena that may not be observable—for example, spectra are based on the bond vibration model.

APPENDIX C

Lesson Plan Template

Materials and Classroom Environment

Printed materials:	Books, handouts, graphic organizers
Technology/Resources/Supplies:	iPads, internet, smartboard, lab
Classroom environment:	Room arrangement, lab space, environment of respect and rapport, culture of learning, classroom policies and procedures, student behavior expectations.
Accommodations for exceptionalities:	Differentiation for all students including EL, SpEd, G/T and 504
Evidence of cultural relevance:	Learning activities and instructional strategies are designed based on knowledge of students' skills, interests, cultural backgrounds, language proficiency, and exceptionalities. How are rigor, relevance, relationships and student voice addressed?

Goals

Content Objective(s):	**Standards:**
What will students know or be able to do at the end of the lesson? Is it measurable?	To be taken from the IB Chemistry Syllabus (Table 1)

Academic Language Demands

Content-Specific Language:	What key vocabulary ("the bricks") do you need to introduce/review with students and how will you engage students with that vocabulary in the lesson? Is this vocabulary being introduced, developed, or reviewed in this lesson?
Academic Language Functions:	What are the students doing with language to express their developing understanding of the content you are teaching? The language functions for science are: analyze, explain, interpret, justify with evidence.
Linguistic Forms:	What words and phrases ("the mortar", language and phrases typically invisible to native speakers) do students need in order to express their understanding of the content you are teaching? How will you teach students the grammatical constructions?
Opportunities for Practice:	What opportunities will you provide for students to practice the new language and develop fluency (written and/or oral)?

Lesson Sequence

Access Prior Knowledge	**Student engagement**
Possible strategies: ● Review of previous lesson	Student engagement strategies:

• Pair and Share • Brainstorming • Quick Write • Verbal check-in of prior knowledge • Visual to access prior knowledge	• Student groupings - pairs, small groups, whole group • Questioning techniques • Discussion techniques • Cooperative activities
New Information	**Student engagement**
Possible strategies: • Modeling and direct instruction • Student discussions • Academic feedback to students • Non-fiction writing, vocabulary and reading strategies to develop understanding of new information • Inquiry based questions and activities	Student engagement strategies above
Application	**Student engagement**
Possible strategies: • Guided Practice • Independent and group work • Student demonstration of learning objective • Student-to-student discussions using accountable talk • Ongoing checks for understanding • Continuous academic feedback to the students	Student engagement strategies above
Goal Review (Assessment)	**Student engagement**
Possible assessments: • Oral or written summary of lesson • Exit slip or quick write • Pair and share • Peer and individual review of work • Class discussion of topic • Cornell notes check	Student engagement strategies above

Post-instructional Reflection

How did the lesson go? Successes? Challenges?	
Did students meet the goal? What is the evidence?	
What changes would you make? How would this improve student learning?	

Figure 2. Lesson Plan template with general descriptions for each section.