Student Use of Historical Context in Science Education to Learn Science Practices

Nathan Van Dyke

A senior thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Bachelor of Science

Adam Bennion, Advisor

Department of Physics and Astronomy

Brigham Young University

ABSTRACT

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Nathan Van Dyke
Department of Physics and Astronomy, BYU
Bachelor of Science

We investigated how students use historical context in a science class to better understand the role of historical context in science education. The research team worked with a class of 38 students at BYU that focused on the History and Science of the Atomic Bomb. The students were given pre-class quiz questions that focused on at least one of the 8 Next Generation Science Standards (NGSS) science practices, and their responses were recorded and analyzed. We found that most of the students, between 55% and 65%, regularly used examples from the course materials as evidence to support their claims about the NGSS practices. Additionally, more students began making real-life connections through the semester, with about 70% of students including some kind of real-life connection in their responses by the end of the semester. The conclusion seems to be that students use the historical accounts of scientists to define their understanding of scientific discovery.

Keywords: Science Education, Historical Context, Science Practice

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Adam Bennion, and Dr. Chris VerHaaren for providing me with this opportunity to investigate this topic. I would also like to thank Ethan Harris for his contributions to the question generation and Maggie McDonough for her contributions to the data analysis. I would also like to thank my wife, Kylie, for her never-ending support and encouragement to help me stick with this project. I would also like to thank God for providing me with this opportunity to not only research science education, but to get to know all of the people that contributed to this project. Additional thanks to F.D.C. Willard for his contributions to the discussion.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

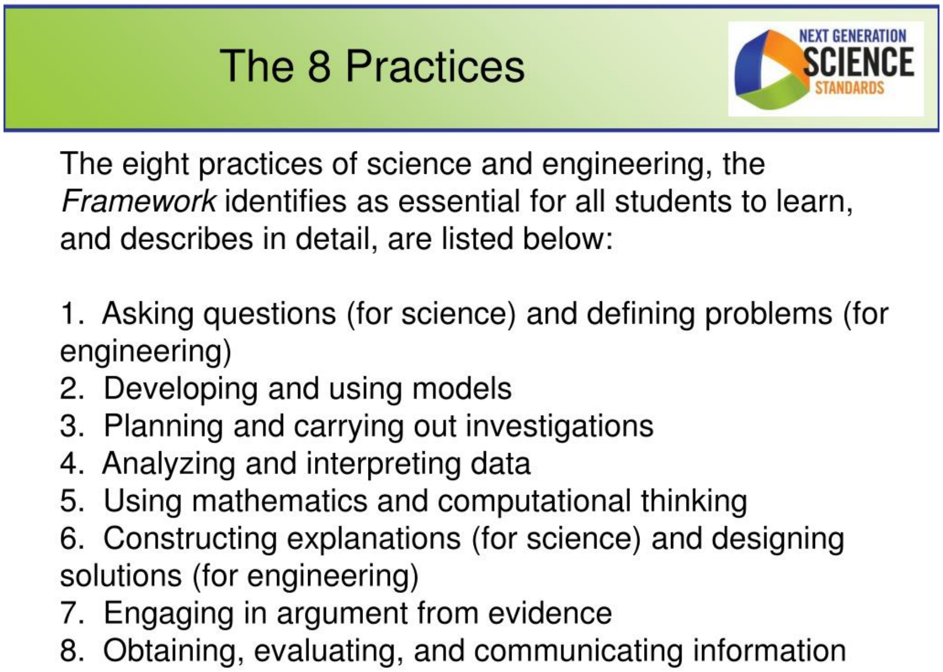
Science education has traditionally been very lecture-based, but recent research has shown that there are better ways for students to learn practical knowledge (Lien, 2024). Students tend to learn better when they are given a chance to explore new concepts and ideas rather than being told what the correct understanding is, and can even develop their own worldview that they can back up effectively with evidence (Chin & Osborne, 2010).

This research on student learning through exploration has become the basis for the development of new science education frameworks , such as the Next Generation Science Standards (NGSS) , which are similar to standards that have been adopted in education systems around the world, according to the National Research Council ([NRC], 2012). An ongoing study, the Trends in International Mathematics and Science Study (TIMSS), has been monitoring the use of various science standard systems in 64 total countries as of 2023. All of the monitored standards systems share a similar practice-based focus, much like NGSS (von Davier, Kennedy, Reynolds, & et al, 2024). The study has been collecting data since 1997, and publishes updates every 3 or 4 years, with the most recent publication being released in 2023. This framework consists of 8 science practices , which are listed in Figure 1.1, with the goal of teaching students realistic science practices that they can then use to learn scientific knowledge. This moves away from the traditional lecture style of teaching and presents a less rigid approach of "authentic science" ([NRC], 2012). This style of teaching has already been successfully implemented at the K-12 level (Herrenkohl & Cornelius, 2013).

As this framework teaching style has become more common, being adopted directly by 20 US states (*Have all 50 states adopted NGSS?*, n.d.), there have been other additions to science education brought to the forefront. Recent research has focused on the use of historical context in science education , such as teaching science through "science stories" that tell a more wholistic picture of the history of science (Güler & Ünal, 2021). The idea behind this concept is that students can better understand how scientists have made discoveries over the years and look for practices that have been used throughout the ages.

Another reason for incorporating historical context is the crossover between traditional science practice and historical practices, the ways in scientists and historians go about procuring new knowledge (Park & Cho, 2022). Both scientists and historians search for truth by means of inquiry, exploration, data collection, sense-making, and argumentation. They both use these general processes to conduct, refine, and share their research. As students are exposed to scientific discoveries and the historical context wherein those discoveries were made, they can more easily recognize similarities between the two (Fischer, 2014).

The purpose of this study was to investigate further into the concept of adding historical context in science education to better understand how historical context improves students' learning. I followed an interdisciplinary course at Brigham Young University that consisted of 38 students, and recorded their progression of understanding of the 8 NGSS practices, outlined in Figure 1.1, throughout the semester. I also had them self-reporting on their understanding of the intersection of scientific and historical practices, and their interest in science as a whole. I also asked them to self-report on their understanding of ethics and the role it plays in scientific discovery, as well as gave them opportunities to share their moral reasoning through historical examples.



The 8 Practices

The eight practices of science and engineering, the *Framework* identifies as essential for all students to learn, and describes in detail, are listed below:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Figure 1.1 New science and engineering practices as outlined in *A Framework for K-12 Science Education* . These will be referred to throughout the paper by abbreviations with a corresponding number. For example, Asking Questions will be referred to as SP1, short for Science Practice 1.

The research was guided by these 3 questions:

1. What intersections can students identify between scientific and historical practice?
2. How do students use historical context to learn scientific principles and practices as outlined by NGSS?
3. How do students use historical context to develop an understanding of ethics ?

Chapter 2

Literature Review

2.1 Intersection of Scientific and Historical Practice

Using the definitions of science and history practices as outlined in the Introduction (Herrenkohl & Cornelius, 2013), we will look at the intersectionality or crossover of both sets of practices. History practice is traditionally used to piece together the most wholistic and accurate account of historical events (Herrenkohl & Cornelius, 2013). Science practices, as outlined in this paper, are structured to create the most accurate explanation for the workings of the natural world as we know it ([NRC], 2012). Although these two goals differ in the sense that they are not seeking the same truth, they are both seeking the truth (Pekdağ & Azizoğlu, 2018). The driving factor is the practice of inquiry, which is more than simply being curious, it entails questioning new ideas. Students tend to grasp this concept best when they can practice it in a classroom setting as part of their learning process (Sandoval, 2005).

These practices both center on the concept of learning by inquiry and constructing answers from evidence. One key component from both is the ability to argue claims based on evidence, which requires certain types of questions (Chin & Osborne, 2010). These evidence-based claims are not always airtight or perfect and contain some level of uncertainty. Understanding that everything in life has some degree of uncertainty helps students to more comfortably question the claims they are confronted with (Metz, 2004).

In addition to simply questioning new ideas, students need to learn how to defend their own ideas, something that requires argumentation skills (Herrenkohl & Cornelius, 2013). This is one of the main crossovers between scientific and historical practice, as both require researchers to defend imperfect claims and ideas (Park & Cho, 2022). This practice of scientific debate and the defense of ideas has been shown to be most effectively taught through practice in the classroom, with students being put in a position of needing to defend their answers (Herrenkohl & Cornelius, 2013).

2.2 Science Courses in a Historical Context

There are 3 main outcomes from using historical context in science education : increasing interest in history, improving academic performance, and teaching scientific literacy. Each of these will be discussed below.

Increasing Interest in History

This first point is helpful, but not central to this study. Research has shown that exposure to historical context in science education increases interest in history, which also increases academic performance (Pekdağ & Azizoğlu, 2018). Additionally, this more wholistic approach to "science stories" increases students’ motivation to engage in classroom activities and learning (Güler & Ünal, 2021). The term "Historical Science Stories" (HSS) comes from a study conducted in Turkey, with the 35 participants being pre-service science teachers. Of the 35 participants, 34 of them found the HSS to be a very engaging teaching strategy and planned to implement it in their own classrooms.

Improving Academic Performance

A 2018 study was conducted among university students in an elementary science teacher program at a university in Turkey, consisting of 90 total students that were randomly divided into 2 separate classes. This study showed that the addition of historical context in a science classroom results in a statistically significant increase of academic performance (Pekdağ & Azizoğlu, 2018). An understanding of the nature of science and scientific research also helps students establish interdisciplinary connections, which allows them to achieve a more mature understanding of theory-building (Teixeira, Greca, & Freire, 2012; da Vitória Gomes, Sivico, & Mendes, 2022). This understanding of the nature of science stems from older forms of philosophy, and has proven useful in classroom settings for both engaging students and creating a culture centered around philosophy and the history of science (Klopfer & Aikenhead, 2022; Galili, 2022). Another way this more profound understanding can be developed is by restructuring the concept and classroom practice of investigation to make the practice more authentic and require the students to engage in more critical thinking and problem solving (Manz, Lehrer, & Schauble, 2020).

Teaching Scientific Literacy

Scientific literacy is typically defined as one's ability to interpret scientific knowledge and findings (Lampert, 2020). This skill is one that is best developed through exposure and practice in the classroom, and develops alongside critical thinking skills (Lampert, 2020). This extends beyond simply being able to read a scientific paper into the realm of simply understanding the implications of scientific discoveries. If students can learn about the impacts that past discoveries have had, they can better anticipate the impacts of new technologies as they arrive (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). Additionally, students can better learn how to interpret and understand contemporary theories, allowing them to engage in personal research and even debate on topics that may be new to them (Lessel, 2024).

2.3 Student Views on Ethical Implications of Scientific Research

Another outcome from added context in science education is the concept of ethics . A framework for moral education as part of science education was put together by a research team in 1995 (Narvaez & Rest, 1995). This framework has been used by researchers since then and consists of four main components: moral sensitivity, moral reasoning and judgment, moral motivation, and moral character.

Moral Sensitivity

Moral Sensitivity is essentially the student's ability to identify an issue as a moral or ethical issue, and typically depends on the perceived closeness to the stakeholder, or subject that stands to gain or lose something as a result of the issue (Narvaez & Rest, 1995). This component is best learned through case study examples and students will typically be most involved with issues that touch on their personal beliefs (van der Leij, Goedhart, Avraamidou, & Wals, 2024).

Moral Reasoning and Judgment

Moral Reasoning ties back into the evidence-based argumentation science practice and is essentially the same idea with a twist. With moral reasoning, there is no right or wrong answer, as the evidence in question consists of the differing perspectives and values. This component requires a classroom environment that provides the students with enough comfort and security to openly express their thoughts (Narvaez, 2021).

Moral Motivation

Moral motivation is where the previously mentioned components begin to take root in the student's understanding and personality. Moral motivation is a student's drive to act on newfound moral and ethical beliefs, developed through understanding an issue and then discussing it (van der Leij, Arvaamidou, Wals, & Goedhart, 2021). Moral reasoning is where the students discuss what possible actions can be taken, with moral motivation being the pillar responsible for carrying out those proposed ideas. For issues that are deemed unimportant, there's no engagement beyond the moral reasoning component.

Moral Character

Moral character is a student's ability to shift and alter their personal moral beliefs to align with a larger community belief, such as a chosen belief that all life is sacred, and should be treated as such. This moral character was shown to be a result of students undergoing the entire "moral process" as laid out in the previous three components (Narvaez, 2021).

One important aspect to note with this "moral process" is that it was applied to real-life scenarios, with real outcomes. Doing this helped the students relate to some of the dilemmas, which can be shown in the ascribed levels of importance that the students gave to the issues presented (Gutmann, Ochoa-Madrid, & Olmstead, 2020).

2.4 Summary

In the real world, scientists need to account for all of these different pieces mentioned, from the practices they use in their data collection and exploration processes to the ethical implications of their research. In order to create the most authentic science learning experience, all of those factors should be taken into account in the classroom, and presented to the students in such a way that the students can learn through doing.

Chapter 3

Methods

In this study, we collected qualitative data on student understanding of historical and scientific practices in a sophomore level science and history course, consisting of 38 students from various majors. We interpreted and analyzed the data interpreted using mixed-method analysis of both qualitative and quantitative information.

3.1 Context

We conducted the study in a science and history course at Brigham Young University, specifically the Science and History of the Atomic Bomb. We used the original pre-class reading quizzes from the course to administer questions specifically geared toward one or more of the eight NGSS practices previously outlined. There were 40 total quizzes, and we included one NGSS question in each quiz. Their responses were recorded via the online homework platform and open-coded to identify trends in student understanding and learning throughout the course.

The course uses the book *The Making of the Atomic Bomb*, by Richard Rhodes, which gives an extensive account of the development of nuclear physics from the earliest discoveries of the atom to the start of the Cold War. The purpose of this course is to help students explore unities between physical science and culture and to help them gain understanding and skills to engage in real-life questions. This is part of the Honors program, which is available to all students, regardless of major.

3.2 Participants

There were 38 total students in the class, most of whom were at the sophomore or junior level in their respective degrees. All of the students in the course were part of the Honors program and had completed at least one Honors interdisciplinary course prior to this study. The research team informed the students at the beginning of the semester that their written answers to the final question on each of the preclass quizzes would be recorded for our use, and that any information shared would be kept anonymous. We have continued to maintain that anonymity and will refer to students' unique, 4-digit course ID numbers, which were randomly generated for this course, and remained constant throughout.

3.3 Data Collection

The research team and I used the reading assignments to develop the pre-class quiz questions, based on identified practices. We collected the written responses via the course website and organized them by quiz question.

We used the reading assignments for the pre-class quizzes to generate questions that focused on one or more NGSS practices. We read and annotated each of the reading assignments, identifying any examples of NGSS practices, and using the most prevalent ones as the focus for each question. For example, the reading for preclass quiz 3 had several examples of Developing and Using Models (SP2), and Planning and Carrying Out Investigations (SP3), so we wrote a quiz question that focused on those 2, which can be found in Appendix B.

The student responses to those questions were then collected through the BYU MAX Learning

Management System (MAX LMS), and organized by question, with the only identifier for each response being the unique 4-digit ID number.

There was also an end-of-course survey administered to the students that consisted of two parts. The first part contained 6 Likert, scaled response questions with students stating their agreement to the statements on a scale from 1 to 5. The second part of the survey contained 5 free response questions that focused on the students' views of history and science as a result of the course. The questions for both parts can be found in Tables 3.1 and 3.2 below.

Table 3.1 Likert questions from the end of course survey.

As scientists (or anyone) develop new theories and technologies, it is critical that they consider the ethical and social implications of the outcomes of their work.
It is unfair for historians (or anyone) to apply modern ethics and standards to past events, scientific and otherwise.
Governments should control the release and dissemination of sensitive research.
Scientists primarily work to refine and develop new models.
Historians primarily work to uncover true accounts of past events.
Neither Scientists nor Historians are responsible for the way their research is used.

Table 3.2 Free response questions from end of course survey.

In this course you have considered the development of the atomic bomb through historical and scientific lenses. Describe the similarities and differences in the way that historians and scientists approach their research:
Take a moment to reflect on how your understanding of history, physics, and nuclear arms has changed over the course of this class. In what ways has your understanding changed? If it is not changed, why do you think that is?
How has your perspective on how science and research progress within society changed because of the things you have read about and discussed in this course.
How can (or should) scientists and historians manage the ethical aspects of their research?
World war two is associated with enormous loss of life, some of which we have considered in detail in this class. With this in mind, what reasons for hope have you noticed during your studies this semester?

3.4 Data Analysis

The research team and I open-coded the written responses from the end course survey to identify common ideas and record the frequency of those ideas. The data from the end course survey was primarily used to answer the first research question about intersections between science and history practice.

The data collected was primarily qualitative in the form of open-ended responses, but also consisted of quantitative survey responses. Because of the combination of the two, we used mixed-methods analysis to interpret it. We started the analysis by coding the end of course survey questions, using an open-coding method. Our open-coding method started with reading the first 10 to 15 student responses to a question and marking any main ideas or themes the students had written. We recorded the most common ideas across those 10 to 15 responses and used binary coding to determine whether or not each student response included that same idea. We repeated this process for each free response question.

I coded the preclass reading quizzes after that, using a similar process. Because we were focused on how the students gained an understanding of the NGSS practices, I focused the open-coding to identify common ideas about those practices. We only had data from a total of 39 preclass quizzes, which would only amount to 4 or 5 quizzes for each practice if we were to focus on only one practice in each question and give each practice the same attention. However, this was not feasible due to the nature of the course material, meaning that some practices garnered much more attention than others, and several of the questions touched on more than one practice. To address this issue, I decided to reclassify the practices into 3 groups. The first group, heretofore referred to as the "Inquiry Practices", consists of Asking Questions (SP1), Developing and Using Models (SP2), and Planning and Carrying Out Investigations (SP3). The second group, the "Sense-making Practices", consists of Analyzing and Interpreting Data (SP4), Using Mathematical and Computational Thinking (SP5), and Constructing Explanations (SP6). The third group, the "Results and Communication

Practices" consists of Engaging in Argument from Evidence (SP7) and Obtaining, Evaluating, and Communicating Information (SP8).

3.5 Limitations

This study had a sample size of only 38 students and could not be expanded. The course chosen is a relatively exclusive one, as it is only offered to Honors students, and is capped out at 45 total spots. In addition, this course is only taught in the winter semesters, which means that it is only taught once a year. This was also the first time anyone had surveyed the students to specifically look at their understanding of science practices as outlined by NGSS. The lack of previous research meant that we were starting the project with little scaffolding to build on with regard to NGSS practices and their prevalence in the course material.

Chapter 4

Results

4.1 Intersections Between Science and History Practice

At the end of the course, we asked the students to fill out a survey that contained some questions regarding the similarities and differences in historical and scientific practices. The first part of the survey contained the Likert questions found in Table 3.1. The second part contained the free response questions found in Table 3.2. The responses were coded to find any common ideas from the students, which are shown in Table 4.1.

Table 4.1 Similarities between scientists and historians as identified by the students. The second column is the percentage of students who gave the definition in their written response.

Both scientists and historians use a practice approach	54.1
Their goal is to seek truth or knowledge	48.6
Both share their discovered information	16.2
Both use a peer review process to ensure accuracy of information	21.6
Both build upon prior work	18.9

This data shows that a large portion of the students recognize similarities in the goals and practices of scientists and historians. 54.1% said that both scientists and historians use a practice approach, and many students explained that they believed the practices of inquiry, data collection/analysis, and argumentation are virtually the same between the two disciplines. One student explained that one "similarity between the disciplines of history and science is that the research conducted in both fields begins with a question. While due to the nature of the disciplines, the question is be different, the beginning spark of each project is to answer some new question" (Student 8387). That was the only similarity identified by a majority of the students, but the other similarities do fall in line with other research (Park & Cho, 2022).

Table 4.2 Differences between scientists and historians as identified by the students. The second column is the percentage of students who gave the definition in their written response.

Scientists construct models while historians construct narratives	43.2
Scientists and historians use different data sources	54.1
Scientists and historians use different forms of analysis	35.1

The differences mentioned weren't as numerous, but were more consistently identified by the students. 54.1% explained that scientists and historians use vastly different sources of data, with scientists using more empirical data obtained through experimentation, while historians use more subjective data in the form of written accounts of historical events.

4.2 How Do Students use Historical Context to Learn Scientific Principles and Practices as Outlined by NGSS?

4.2.1 Inquiry and Exploration Science Practices

Over the semester, the students developed their own definitions of each NGSS practice. This section covers the first three practices, found in Figure 1.1, as the "Inquiry and Exploration" group from the Introduction, which will be referred to as the Inquiry group. For each practice, I identified common themes from student responses. These are generalized ideas that represent a coded topic from the quiz coding. These definitions are not exact wording from the students but capture overarching ideas and definitions about each of the listed practices.

Use of Historical Examples

Table 4.3 Student definitions of SP1: "Asking Questions".

Questions are often spurred by interest in some phenomenon that is unknown of not fully understood
Variety of questions can be limited by tunnel-visioned thinking

Table 4.4 Student definitions of SP2: "Developing and Using Models".

Models must be based on foundational research
Adherence to older models can inhibit exploration
Models are often used for theory-building
Models can be used for partial reasoning/understanding
Models are developed step-by-step and can be refined by experimentation
Models can be used to guide experimentation

Table 4.5 Student Definitions of SP3: "Planning and Carrying Out Investigations".

Continued experimentation can overcome research roadblocks
Funding and feasibility of experimentation can be limiting factors
Investigation provides evidence used for theory-building
Discovery is often accidental and doesn't come from a cookbook
Experimentation can be used to prove mathematical and conceptual models
Good investigation requires attention to unexplained/unexpected results

Focusing on the Inquiry and Exploration group, we identified trends in the use of historical examples, real-life applications, and crossover between those, defined as answers wherein the students used a historical example either as evidence to support their claim or related it to personal experience.

We found little correlation between time in the semester and the use of historical examples. There was one significant spike in historical example usage, around quizzes 25 and 28, which both focused on the Manhattan project and the safety/functionality of the different research and production facilities. This did not coincide with a spike in real-life application, but did coincide with an increase in expression and definition of students' ethical codes and moral understanding.

While there was no significant increase in the use of historical examples, the average usage

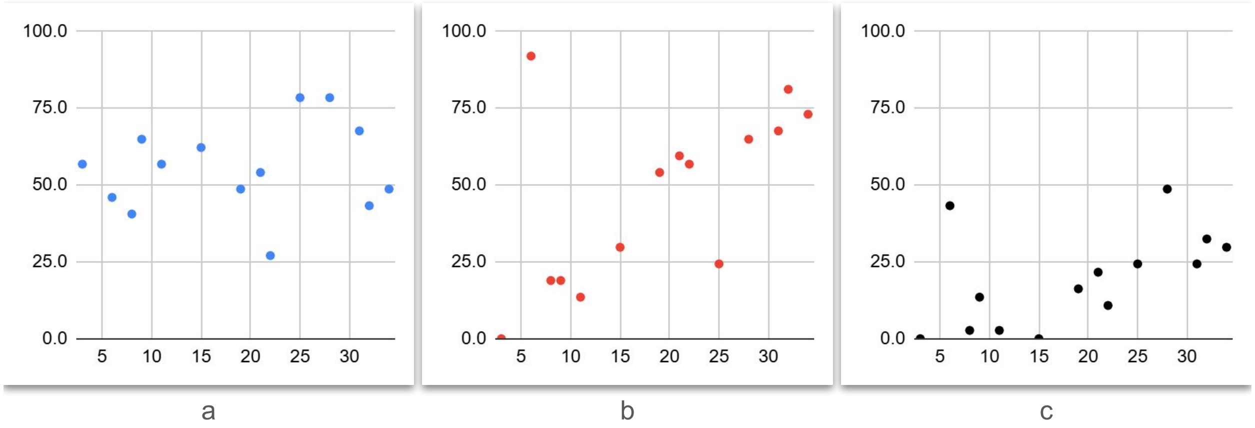


Figure 4.1 Graph (a) shows the percentage of students incorporating historical examples as they progressed through the quizzes. Graph (b) shows the percentage of students incorporating real-life applications as they progressed through the quizzes. Graph (c) shows the percentage of students that used a combination of both historical examples and real-life applications as they progressed through the quizzes.

was fairly high with about 56% of the students using a historical example in their answers on any given quiz from this group of NGSS practices. This suggests that many of the students are utilizing historical examples from the course materials to help them develop their answers about science practices.

Real-Life Application

There was a significant increase in real-life application as the semester progressed. This was primarily due to students answering questions with their own developed understanding of the practice they were referring to. For example, in response to the question "How do scientists determine if a new question is worth investigating?", one student explained "...they evaluate if the question addresses gaps in current knowledge, if it could lead to practical applications or new advancements, and if it's feasible to investigate given available resources and technology. Additionally, they might assess the novelty of the question and its ethical implications..." (Student 4010). The increase in real-life application answers can be attributed to the students exposure to specific examples from the course literature. As stated before, there was no significant increase in the use of historical examples, but they were still very prevalent in the student responses.

This consistent use showed to be a factor in the increase of real-life application. Students began to use those historical examples more as evidence to support their claims and opinions about each of the science practices. This is what led to the increase in the crossover between the use of historical examples and real-life applications. These examples were also used by the students to defend their moral standings, which will be discussed later.

4.2.2 Data Analysis and Sense-making Practices

I combined the next three practices, see Figure 1.1, into the "Data Analysis and Sense-making" group, referred to as the Sense-making group. Similar to the Inquiry group, these definitions come from students' written responses to pre-class quiz questions. I have adjusted them from the students' exact phrasing to encompass more generalized definitions or ideas about each practice.

Table 4.6 Student definitions of SP4: "Analyzing and Interpreting Data".

Data analysis explains collected data
Sometimes results don't match the model
Too much raw data can get complicated
Some conclusions can guide further data collection
Analysis can provide an accurate understanding of reality
We can still learn from partial or incomplete data

Table 4.7 Student definitions of SP5: "Using Mathematics and Computational Thinking".

Mathematical modeling guides experimentation
Mathematical models are more easily developed
Testing accuracy of mathematical models require known quantities
Mathematical models are more easily replicable
Mathematical models are often more precise than conceptual models

Some of the key concepts from SP4 were that the analysis is essentially the explanation of the data, too much data can be a bad thing because it can overcomplicate the analysis, and even partial

Table 4.8 Student definitions of SP6: "Constructing Explanations".

New theories can be constructed by fitting pieces together
Problem-solving
Accurately constructed explanations can help to inform decision-making
Explanations are used to answer initial exploratory questions
Constructing explanations can lead to new understanding
Collaboration when constructing explanations can lead to faster discovery

data can be useful. On most occasions when the students discussed this practice, they focused on the importance of explaining the data set as a whole including any outliers, and making sure that the data is accurately explained and any adjustments to known models are made when data suggests a change is necessary.

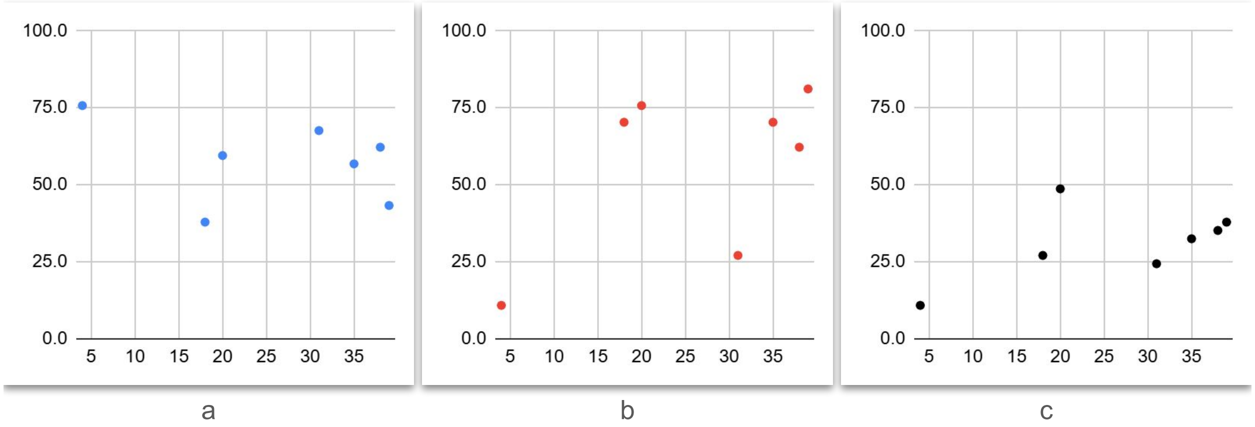


Figure 4.2 Graph (a) shows the percentage of students incorporating historical examples as they progressed through the quizzes. Graph (b) shows the percentage of students incorporating real-life applications as they progressed through the quizzes. Graph (c) shows the percentage of students that used a combination of both historical examples and real-life applications as they progressed through the quizzes.

Use of Historical Examples

Similar to the Inquiry group, there was no clear trend of correlation between semester progression and use of historical examples. Although there was a wide range of the percentage of students who used historical examples in their responses, the average changed very little as the course progressed, staying around 56%. This is similar to the average percentage from the Inquiry group, which averaged 55%.

Real-Life Application

The extent of real-life examples in this group of practices also shows little evidence of an upward trend. With the exception of quiz 2 and quiz 31, all of the quizzes showed about 60% to 80% of students using some sort of real-life application in their responses. Even though there is no clear upward trend, as with the Inquiry and Exploration group, the average is still notably high, with more than 50% of students incorporating real-life applications into their answers in 5 out of the 7 quizzes in this practice group. The other two quizzes had very high percentages of historical examples, which suggests that the students likely relied more on that than on real-life connections.

Additionally, this group did show a slight upward trend between the use of both historical examples and real-life connections. This suggests that, while the percentages of students using historical examples or real-life connections didn't increase, the percentage of students utilizing both did increase.

4.2.3 Results and Communication Practices

I grouped the final two practices, see Figure 1.1, into the Results and Communication group, which will be referred to as the Results group for the remainder of this section. Although there were only 2 NGSS practices in this group, it covered the largest number of quizzes, and each practice had very well-defined definitions. These definitions are summarized generalizations based on the student responses.

The key takeaway from the definitions of SP7 is the importance of open communication and healthy debate. This means not only providing a physical means whereby information can be shared, but by also creating a culture that promotes constructive criticism and healthy debate. There were

Table 4.9 Student definitions of SP7: "Engaging in Argument from Evidence".

Competing theories can be reconciled through evidence-based argumentation
Uncertainty within a given model can be the source of scientific debate
Fear of contradicting accepted models can inhibit the publishing of discoveries
Challenging of ideas should be welcomed by a scientific community
Open argumentation can increase accuracy and credibility of findings
Differing perspectives can be very beneficial to identifying possibly breakdowns in theories
Argumentation and discourse can be stifled by narrow-minded individuals

Table 4.10 Student definitions of SP8: "Obtaining, Evaluating, and Communicating Information".

Societies communicate discoveries to the general public
Open communication promotes public trust
Fear of opposition or criticism can inhibit communication
Collaboration can provide a "sounding board" for scientists
Some information can be rushed by the pressure of someone publishing first
Scientists and the general public are both responsible for bridging any communication gaps
Communication of discoveries should be objective and unbiased
Mutual respect is required for open and effective communication
Wartime secrecy can inhibit scientific advancement by eliminating communication and collaboration
Communication of discoveries can help expand technological applications
Accuracy of information is the most important aspect of any information shared

a few stories from the course text that were cited by the students as examples of situations that inhibited the free discussion of new ideas, and each of those lead to a delay in publication of new information, one example of that being the discovery of nuclear fission.

There were multiple key takeaways from the SP8 definitions, the main ones being the importance of unrestricted communication, the benefits of collaboration, and the importance of mutual respect and objectivity. Many of the students contrasted the amount of collaboration before and during WWII, showing how each of those scenarios greatly affected global scientific advancement.

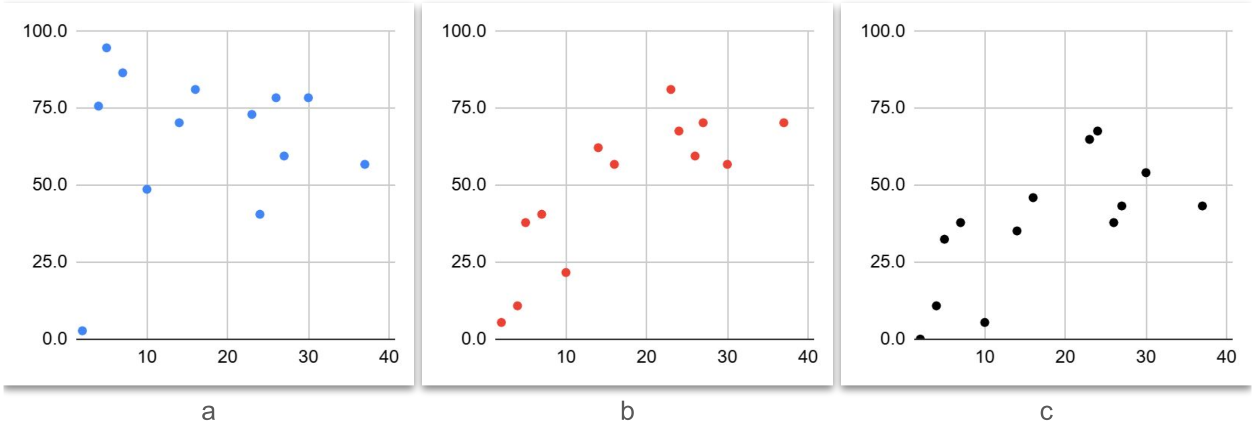


Figure 4.3 Graph (a) shows the percentage of students incorporating historical examples as they progressed through the quizzes. Graph (b) shows the percentage of students incorporating real-life applications as they progressed through the quizzes. Graph (c) shows the percentage of students that used a combination of both historical examples and real-life applications as they progressed through the quizzes.

Use of Historical Examples

The overall use of historical examples was higher for this group of practices than the other two, with the average being 65%. There is also a very sutble decrease in the use of historical examples as the course progressed. Even with this slight decrease, students used historical examples to help explain their answers much more on these two practices than the other 6. It's possible that the subtle decrease could be students shifting away from using historical context and utilizing more real-life connections in their responses.

Real-Life Application

The Results group saw the fastest increase in the percentage of students using real-life connections. This group was a little unique in the sense that most of the real-life connections were students explaining their own understanding of these practices and how they thought the scientists in the course readings should be implementing them. There were not a larger quantity of story-like examples in this group than the previous two, rather there were more opinionated responses where the students explained their understanding of the science practices based on their own experiences.

The most intriguing trend is that this group had the highest percentage of students utilizing both historical examples and real-life connections in their responses. The percentages quickly rose, with between 35% and 75% of the students using both historical examples and real-life connections in 6 of the last 7 quiz questions that focused on these two practices. The students seemed to be most opinionated about this practice group than about the other two, as they were using more evidence to support their claims.

4.3 How Do Students use Historical Context to Develop and Understanding of Ethics ?

4.3.1 Role of Ethics in Scientific Exploration

During the course, the students pieced together their own understanding of ethics and the role of ethics in scientific exploration. The common themes are listed in Table 4.11, with the percentage of students that discussed that theme in the second column.

Table 4.11 Student explanations of the role ethics plays in scientific exploration.

Student claims with percentage of students	%
Mutual respect between scientists and researchers promotes collaboration	64.9
Experimenters should work to reduce collateral damage from potential dangerous experiments	75.7
Researchers should always consider risk vs reward	37.8
Researchers should focus on potential benefits and improving quality of life of technology instead of exploring malicious uses of technology	18.9

There were two roles that the majority of the students talked about. The first and most common was the importance of working to reduce collateral damage when experimenting. Nearly all of the students that discussed this point used the example of the Trinity test and the resulting fallout to address the importance of designing and maintaining safeguards that can fully contain any potential adverse effects. During the Trinity test, there was no way to contain the airborne fallout that came as a result of the nuclear explosion, which contaminated nearby towns.

The second most common role is that mutual respect between scientists and researchers. The students often cited examples of disagreements between researchers that led to rifts in their relationships, and talked about how a lack respectful communication can push researchers out of a project and possibly remove some useful insight as a result. Additionally, several students talked about their own experiences in group projects throughout their schooling and how they often worked better when everyone was willing to listen to and discuss ideas rather than immediately dismissing them in a manner that can be belittling.

The other two major roles are somewhat complementary and were seen as very important by the minority of the students that addressed them.

4.3.2 What Ethical Responsibility to Scientists Have?

This course presented the students with a unique perspective on the history of nuclear research during WWII by showcasing scientific and political perspectives from all sides of the conflict. This allowed the students to obtain enough information to develop their own opinions on which decisions they perceived to be right or wrong. The latter half of the course focused on the Trinity test and the use of nuclear weapons during WWII, as well as the variety of nuclear treaties proposed and signed after the war. Because of that focus, I incorporated an element of ethics discussion into those later quiz questions (quizzes 32 through 39). Some of the questions presented the students with hypothetical scenarios concerning the Los Alamos research facility and others directly asked for their opinions on certain political acts and statements (such as the decision to drop the bombs on

Japan). More specifically, the questions focused on the responsibility and role of the researchers in each of these situations and how that relates to scientific exploration as a whole.

One example was from quiz 32, where we presented the following question: "What kind of responsibility would the experimenters have in the event of an accident causing civilian casualties and collateral damage?" The majority of student responses agreed that is primarily the role of the researchers to ensure that safety guidelines are set up in such a way as to minimize the risk of collateral damage. One student expressed their opinion on how the responsibility could differ slightly depending on the situation, "If there were a totally unexpected side effect, such as a larger than anticipated seismic wave that destabilized a weak building outside of the believed danger zone, the scientists would carry less responsibility. If the experimenters were found to have flagrantly ignored a reasonably predictable danger, they would carry much more responsibility and ought to have greater penalties attached." (Student 7022). Essentially, researchers are the ones who are most knowledgeable about the capabilities of their research and should therefore be held accountable for making sure that all precautions are taken.

Another example comes from quiz 36, where we presented the following question: "After World War II Curtis LeMay continued to focus on napalm based solutions in conflict. How might this kind of tunnel vision affect scientific progress and innovation? What ethical implications might there be?" The most common ethical concern among the students was that hyper-focusing on one solution can limit time and resources that could be used to research and possibly find a better solution. Most of the students who referred to the example of napalm in their responses talked about the mass destruction and devastating loss of life due to napalm weapons, and suggested the need for less destructive alternatives. One student even went as far as suggesting that the money put into napalm meant that the funding couldn't be used for beneficial research, stating that "...you will miss opportunities to achieve scientific advancements. Ethically, if these advancements could have alleviated suffering and saved lives you would be in some way responsible for that suffering."

(Student 1847).

These types of responses from the students show the use and implementation of their own moral codes and understanding, as they are making statements about what they personally think is right or wrong in the given situation. They've all developed some kind of moral reasoning prior to this course, and shown how they would apply it in the world of science. This may have also been the first time that some of these students were asked to do so in situations where there is no right answer and therefore every choice must be justified through argumentation and debate.

Table 4.12 This table reflects the opinions of the students on how scientists and historians can manage ethical implications of their research. The second column is the percentage of students who made the corresponding claim in their written response.

Scientists should think about the potential impact of their research	60.5
Scientists need to keep others/public informed and should conduct research with some level of openness	28.9
Scientists should consult with others and regularly follow some form of peer review	36.8
Scientists should develop ethical codes and a means to hold those accountable that break those codes	21.1
Scientists are not directly responsible for the use of their research and findings	26.3
Scientists and researchers should treat others with respect and dignity	28.9

The data table shown above reflects the common opinions on ethical implications of scientific and historical research and how researchers should consider them. The only one shared by the majority was that "Scientists should think about the potential impact of their research". This is admittedly a very broad concept and was therefore identified by students suggesting different ways in which researchers can consider the impact of their work. One suggestion from a student was that "It's important for them to think about how their findings might affect the world and to make sure they're doing their research in a way that respects everyone involved. By teaming up across different fields, they can make sure their technical goals don't overshadow the historical and ethical big picture." (Student 4094). This suggestion for interdisciplinary collaboration was echoed by many other students and reflects the examples they both saw in the course texts and used in their responses to the quiz questions. The overarching theme and core idea behind this practice being the importance of respecting others and working towards the betterment of humanity.

4.3.3 Application of Ethics Understanding

Another outcome evident in student responses was their ability to view past events with a more holistic view rather than a one-sided view, and to see and understand the various perspectives of everyone involved rather than a simplistic black-and-white problem. On a few occasions the students were even able to apply this holistic perspective to current or more modern events. The question on quiz 38 was "How can the data describing the effects of atomic bombs inform ethical considerations regarding their production and use?", prompting the students to reflect on the political role of scientists when communicating and evaluating information. One student expressed their concern about reducing the loss of life to numbers and how that can distance us from the issue, "I think it's crucial when discussing the ethics and data with atomic bomb use to keep in mind how human brains cannot comprehend much more than 100 or 1000 deaths at a time. Even that is a stretch. We can imagine scenes like 60,000 people in...[a football]...stadium dead, but the space dead bodies take up does not quantify the suffering of the living individuals who were tied to those people. Think of how much sorrow appears at one funeral. Now think about 2. Now 5. Now 10. At some point, it becomes impossible for people to wrap their heads around high death numbers." (Student 9352). This student then compared the destruction of Hiroshima and Nagasaki to the current war in Gaza, and the catastrophic loss of life and irreparable damage done, without expressly choosing a side of the conflict.

Another student on a previous quiz question (quiz 32), when asked about the responsibility of researchers to minimize collateral damage, cited the Chernobyl nuclear meltdown in 1986 as an example of how quickly things can go wrong when dealing with nuclear research, and to support their opinion that "To not strictly follow safety guidelines is to put the risk of experimenters and civilians at risk of radiation poisoning, cancer, and all sorts of harmful effects should the reaction run out of control." (Student 8387). One note about this quote is that the student said "risk of experimenters and civilians", when the intended word was probably lives. This claim is effectively that researchers need to safety guidelines, especially with nuclear research, in order to ensure the lowest risk to the lives of any who may be involved, even just as passers-by.

Chapter 5

Discussion

The focus of this study was to show how students use historical context to learn scientific practices and principles. We used a sophomore-level science and history course to collect our data via pre-class quiz questions that were targeted toward the 8 NGSS science practices. The data then showed us a couple of trends throughout the semester about how the students were using the historical context .

The first trend to notice is actually a lack of any sort of trend between the usage of historical examples over the course of the semester. The students stayed relatively consistent; about 56% to 70% of student answers used historical examples on any given quiz, with no clear rise or fall. This shows that the students will be attentive enough about the historical context to include it in their reasoning more than 50% of the time. This also shows that students do use this context as a source for examples of science practices that they can then use to define their own understanding of what authentic science practices look like.

Another trend was that the use of real-life connections steadily increased across all three NGSS practice groups. These real-life connections manifested themselves in two ways, either the students making a connection to a personal or modern-day example, or defining a practice or idea in their own words. The latter of these two was often accompanied by some historical example from the course used as evidence to support the student's claim. The data shows a somewhat linear increase in the use of real-life connections, as well as the use of both historical examples and real-life connections as the semester progressed. Although it was a steady increase all the way to the end, a longer study might show if there is a peak or limit of some kind, or if any given class can achieve 100% of students making real-life connections and citing historical examples from the course. This increase in real-life connections and students' defense of their answers follows the claim that students best learn to defend their claims through practice in the class (Herrenkohl & Cornelius, 2013). Additionally, they often tied the challenges presented in the course text to more modern issues and examples, showing competency in applying a historical lens to the present (Stuckey et al., 2013).

The increase in use of both historical examples and personal applications shows how the students used the historical context to define each of the 8 NGSS science practices. As the course progressed, the students used the examples they did to explain aspects of each science practice, compounding to create well-defined explanations of each practice. Using the example of science practice 3, Planning and Carrying Out Investigations, the students started with a limited scope of focusing on the importance of equipment, then adding the more modern role that funding plays into it, and finally discussing the non-linearity of scientific discovery. They were able to create an understanding that equipment and technology are your primary limiters, with your source of funding being the primary controller of what you research, and that very rarely does an experiment perfectly yield the expected results, if it even yields the expected results at all.

Another notable result was the students' willingness to state and defend their moral stances on issues that were relatively new to them. While many of them had heard of the atomic bomb and the Manhattan Project, very few of them had had as much exposure to them as they did in the class. Because of that, their moral sensitivity, reasoning, and character regarding the use of nuclear weapons was not very developed. As the course progressed, they became increasingly vocal about their stances on the issue of nuclear weaponry, to the point of applying those morals to modern conflicts, such as the Ukraine and Gaza conflicts. This shows the moral development that comes from being presented with real issues (van der Leij et al., 2024) and being able to discuss them in an environment that encourages them to do so (van der Leij et al., 2021).

5.1 Conclusion

In this study, we set out to show the benefits of adding historical context into science education by showing how it is used in the students' sense-making and application. As shown in previous sections, the historical context became a valuable resource to the students by providing a source of examples that could be related to their personal lives. This connection was then used by the students to define each of the NGSS practices.

The students successfully created their own framework for scientific exploration and discovery, which they also implemented more as the course progressed. The added historical context created an environment for the students to learn scientific practices which they then applied to learn the course content. The students constructed their own worldviews of what scientific discovery looks like.

When the students were presented with new information that gave a more detailed picture of past events and then asked to interpret the morality of the situation, they often addressed both sides of the situation. By adding context, the students were able to see that morality in scientific exploration is often a gray area and requires calculated risks to make progress. After getting exposure to that concept through historical events, like the invention and use of the atomic bomb, they were able to showcase their ability to apply the moral reasoning and judgment they had developed to more modern situations, such as modern conflicts.

5.1.1 Future Research

These research findings are useful, but there is plenty of room to add on to this. The sample size used was very small, and there was no prior data we could have used, since this was the first time any of the created quiz questions were included in the course. In the future, we would like to administer these same questions to the class, and compare the results of each subsequent semester to this data set. This could also give us more feedback from students on how we can adjust the course to better facilitate the learning of science practices.

One of the most important pieces of this course was the classroom environment. There were a lot of opinions shared on scientific and historical practices as well as ethics. In order to truly allow the students to express their opinions and use the course material to defend those opinions, the classroom environment must be such that they are comfortable doing so. With regards to scientific and historical practices, the defense of claims needs to rely on evidence. Such evidence often comes in the form of personal and historical examples, which also requires that the students be comfortable questioning the source and motive as a way to determine credibility of evidence. As for ethics discussions, there should be certain moral pillars that are unanimously agreed upon, such as the sanctity of human life, and the importance of honesty. However, it should not be expected that all of the students agree on specific ethics claims. In this course, some students felt that nuclear weapons are still a necessary deterrent and belong in military arsenals, while others were of the opinion that all nuclear weapons are inherently bad. Both claims are valid, as both are based on personal moral reasoning and can be supported with evidence.

Appendix A

NGSS Practice Definitions

To assist in maintaining uniformity in the open-coding of student responses, as well as the coding of the class readings to develop the quiz questions, we developed the rubric of definitions, found in Table A.1, for the NGSS practices.

Table A.1 Definitions of each NGSS Science Practice used for this study. This rubric was used to code student responses.

1. Asking Questions: - How/why, “what happens if” - Cannot be answered with yes or no, must challenge known principles
2. Developing and Using Models: - Simplify phenomena in a way that can be visualized and understood - Physical model, if necessary and available - Must be able to manipulate (apparatus or equation)
3. Planning and Carrying Out Investigations: - Experimentation: hypothesis, constraints, quality control, data recording
4. Analyzing and Interpreting Data - Must be accurately recorded, discrepancies must be accounted for - No specific way to best interpret, depends on data collected - Must be analyzed in a way that makes sense and can be understood - Typically leads to further experimentation/modifications
5. Using Mathematics and Computational Thinking - Recognize patterns - Describe with equations and mathematical formulas - Statistics
6. Constructing Explanations - Links data analysis and mathematical thinking - Experiment alterations brainstormed - Claim, Evidence, and Reasoning
7. Engaging in Argument from Evidence - Determine if evidence answers original question - What was learned/discovered? - Collaborative
8. Obtaining, Evaluating, and Communicating Information - Compare results from various experimental trials - Final conclusion/verdict - Who needs to know?

Appendix B

Preclass Quiz Questions

Quiz 2 Question: Why should scientific societies ensure that the knowledge gained from experiments is accessible to the general public?

Quiz 3 Question: What were the major challenges and obstacles faced by early chemists in their efforts to refine chemical models, and how did they overcome them?

Quiz 4 Question: How did scientists in the 19th century attempt to reconcile the seemingly contradictory theories of energy conservation?

Quiz 5 Question: Why did Rutherford consider harnessing atomic energy to be "talking moonshine"?

Quiz 6 Question: Thomson's experiments suggested that the electrically neutral atom had negatively charged parts. As a result he developed the "plum pudding" model. Given the data that was available to him at the time, suggest another model that could describe the atom as well as his. How might experiment determine which of these different models agrees more with nature?

Quiz 7 Question: Why was Rutherford hesitant to make his discovered findings public? Is the concern that he had still relevant today?

Quiz 8 Question: Planck's derivation of the blackbody spectrum, Einstein's explanation of the photoelectric effect, and Bohr's model of the Hydrogen atom were all ad hoc, not part of a complete theoretical system. How can incomplete theoretical models like these still be useful in understanding

Quiz 9 Question: How can war time priorities influence scientific developments?

Quiz 10 Question: Bohr, Schroedinger, Heisenberg, Born, Jordan, and others often worked together to develop the principle of quantum mechanics. What is the benefit of collaborating like this?

Quiz 11 Question: Several researchers did not recognize experimental evidence of the neutron when they found it. Contrast the serendipity of scientific discovery with popular conceptions of scientific practices.

Quiz 12 Question: During the late 1930's many scientists were forced to flee Germany and Italy and abandon their positions. How do you think political and social pressures like these influence the work of scientists today?

Quiz 13 Question: Fermi made major contributions to our understanding of the isotopes of atoms but these contributions are often not included in the historical narratives taught about atoms in secondary schools. Why do you think some contributions take precedent in these spaces?

Quiz 14 Question: Considering Ida Noddack's critique of Fermi's claim of the production of transuranic elements, comment on the strengths and weaknesses of the peer review process.

Quiz 15 Question: Lise Meitner and Otto Frischused Bohr's "liquid drop" model of the atomic nucleus. How did they use this model to understand how a neutron can cause fission?

Quiz 16 Question: The theoretical model of Uranium fission was kept somewhat secret until Meitner and Frisch could publish their results. Why was this? What are the pros and cons of waiting for publication in a fast moving field?

Quiz 17 Question: Lindemann was Churchill's science advisor and friend. How might the personal relationship affect the professional advice? What practices could provide better scientific recommendations to politicians and leaders?

Quiz 18 Question: Bohr suggested that Uranium-235 would easily fission based on an incomplete mathematical model. What kind of balance is there between mathematical modeling and physical experimentation in establishing new science?

Quiz 19 Question: One of the biggest inhibitors of further experimentation was the cost. Why might scientists be wary of relying on government funding during a war?

Quiz 20 Question: How did mathematical modeling of critical mass contribute to the possibility of a nuclear bomb? What advantages do mathematical models have over a physical or mental model?

Quiz 21 Question: McMillan's eventual discoveries of Neptunium and Plutonium originally came from him studying decay ranges of Uranium-239 beyond his original research plan. How do scientists determine if a new question is worth investigating?

Quiz 22 Question: Much of the experimentation done to look into the sustainability of a chain reaction was based on past experiments. In repeating and restructuring past experiments, how can you be sure that you are at a point where you can move on versus continuing to confirm your data?

Quiz 23 Question: Copenhagen illustrates the challenges and ethical considerations associated with obtaining, evaluating, and communicating scientific information in a political context. Are the methods used effective scientific communication? How can one foster better communication between scientists, policymakers, and the public in contemporary scientific endeavors?

Quiz 24 Question: Edward Teller describes group interactions: "My theories were strongly criticized by others in the group, but together with new difficulties, new solutions emerged. The discussions became fascinating and intense. Facts were questioned and the questions were answered by still more facts. . . " What are some benefits to a team exercising this practice?

Quiz 25 Question: Fermi's CP-1 had a number of safety features that were built into the design rather than retrofitted after production. What safety features did the pile have and why is it important to have more than one or two safety features in an experiment?

Quiz 26 Question: During world war two, almost all nuclear research disappeared from the usual public journals. What effects can isolation have on research efforts in different countries?

Quiz 27 Question: In the Summer of 1943 John von Neumann, a Hungarian mathematician, came to Los Alamos to help design the implosion bomb. Together, Neddermeyer and von Neumann were able to form a clearer picture of how implosion worked practically and mathematically. Why is it important to communicate and work researchers in other fields?

Quiz 28 Question: The Y-12 isotope separation plant, as described early in the chapter, was plagued with difficulties. Which scientific practices might have prevented or mitigated the problems that arose and why?

Quiz 29 Question: Germany's main source of heavy water was sabotaged, seriously impeding their nuclear program during the war. Why is it important to have a diversified stream of research material and equipment, even in peacetime?

Quiz 30 Question: One important aspect of getting any plutonium and uranium production started was convincing the military (the source of funding) that a particular method was worth the cost. What methods of persuasion were used and why were some more effective than others?

Quiz 31 Question: The pacific airforce employed scientific practices to realize successful bombing missions. What factors were taken into account and what changes were made?

Quiz 32 Question: Discuss the importance of strictly following safety guidelines with large-scale nuclear experiments. What kind of responsibility would the experimenters have in the event of an accident causing civilian casualties and collateral damage?

Quiz 33 Question: In his memorandum Szilard says, "These decisions ought to be based not on the present evidence relating to the atomic bombs, but rather on the situation that can be expected to confront us in this respect a few years from now." What are the benefits and costs of using the possible future to determine present policies?

Quiz 34 Question: Reflect on how best to balance the pursuit of scientific knowledge with the potential benefits and risks involved in nuclear experimentation.

Quiz 35 Question: Curtis LeMay studied photographs from bomber runs and then set out to better understand how much heat the aircraft could take. Dramatic increase in bomber success was the result. Explain why it is important to understand the data you have before setting out for more.

Quiz 36 Question: After World War II Curtis LeMay continued to focus on napalm based solutions in conflict. How might this kind of tunnel vision affect scientific progress and innovation? What ethical implications might there be?

Quiz 37 Question: Surrounding the Potsdam conference were many individual assessments of how to cause a Japanese surrender. How would you have organized the importance or quality of received information to help inform the president to make the best decision?

Quiz 38 Question: How can the data describing the effects of atomic bombs inform ethical considerations regarding their production and use?

Quiz 39 Question: Research such as the effects of the atomic bomb on the populations of Hiroshima and Nagasaki are quite messy. Many experiments seek to implement controlled environments or groups to mitigate error. In spite of the messiness, why is it important to research complicated problems despite the challenges and obstacles?

Quiz 40 Question: Legacies of the Manhattan Project include a decades-long nuclear arms race and the specter of nuclear war. How have these legacies changed the world of scientific investigation?

References

Chin, C., & Osborne, J. (2010). Supporting argumentation through students' questions: Case studies in science classrooms. *The Journal of the Learning Sciences*, *19*(2), 230–284.

da Vitória Gomes, R., Sivico, M. J., & Mendes, A. N. F. (2022). The history of science in an interdisciplinary approach in the curriculum: broadening horizons for building and mediating learning from the nature of scientific knowledge. *Revista de Ensino de Ciências e Matemática*, *13*(6), 1–22.

Fischer, U., Kollar. (2014). Scientific reasoning and argumentation: Advancing an interdisciplinary research agenda in education. *Frontline Learning Research*, *2*, 28-45.

Galili, I. (2022). Scientific knowledge as a culture: A paradigm of knowledge representation for the meaningful teaching and learning of science. *Scientific knowledge as a culture: The pleasure of understanding*, 245–275.

Gutmann, B., Ochoa-Madrid, E., & Olmstead, A. (2020). I'm not that important": Barriers and bolsters to student agency during conversations about the intersections of physics and ethics. *Physics Education Research Proceedings*.

Güler, M., & Ünal, S. (2021). Tell me a story, professor! the effect of historical science stories on academic achievement and motivation in a physics class. *Research in Science & Technological Education*, *41*(2), 635-652.

Have all 50 states adopted ngss? (n.d.). `https://openscied.org/knowledge/have-all-50-states-adopted-ngss/`. (Accessed: 2024-12-11)

Herrenkohl, L. R., & Cornelius, L. (2013). Investigating elementary students' scientific and historical argumentation. *Journal of the Learning Sciences*, *22*, 413-461.

Klopfer, L. E., & Aikenhead, G. S. (2022). Humanistic science education: The history of science and other relevant contexts. *Science Education*, *106*(3), 490–504.

Lampert, Y. (2020). Teaching the nature of science from a philosophical perspective. *Science & Education*, *29*(5), 1417–1439.

Lessel, B. (2024). From history of physics to "history for physics". *The European Physical Journal H*, *49*(Article 19).

Lien, A. (2024). Exploring living nature: Modes of observation in history, teaching and learning. *Doctoral dissertations at University of Agder*.

Manz, E., Lehrer, R., & Schauble, L. (2020). Rethinking the classroom science investigation. *Journal of Research in Science Teaching*, *57*(7), 1148–1174.

Metz, K. E. (2004). Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. *Cognition and instruction*, *22*(2), 219–290.

Narvaez, D. (2021). Moral education in a time of human ecological devastation. *Journal of moral education*, *50*(1), 55–67.

Narvaez, D., & Rest, J. (1995). The four components of acting morally. *Moral behavior and moral development: An introduction*, *1*(1), 385–400.

[NRC]. (2012). *A framework for k-12 science education: Practices, cross-cutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Park, W., & Cho, H. (2022). The interaction of history and stem learning goals in teacher-developed curriculum materials: opportunities and challenges for steam education. *Asia Pacific Education Review*, *23*(3), 457–474.

Pekdağ, B., & Azizoğlu, N. (2018). History-based instruction enriched with various sources of situational interest on the topic of the atom: the effect on students' achievement and interest. *Research in Science Education*, *50*, 1187-1215.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science education*, *89*(4), 634–656.

Stuckey, M., Hofstein, A., Mamlok-Naaman, R., & Eilks, I. (2013). The meaning of 'relevance'in science education and its implications for the science curriculum. *Studies in Science Education*, *49*(1), 1–34.

Teixeira, E. S., Greca, I. M., & Freire, O. (2012). The history and philosophy of science in physics teaching: A research synthesis of didactic interventions. *Science & Education*, *21*, 771–796.

van der Leij, T., Arvaamidou, L., Wals, A., & Goedhart, M. (2021). Biology students' morality when engaged with moral dilemmas in the human-nature context. *Frontiers in Education*, *6*.

van der Leij, T., Goedhart, M., Avraamidou, L., & Wals, A. (2024). High school biology students' use of values in their moral argumentation and decision-making. *Journal of Moral Education*, *53*(3), 388–411.

von Davier, M., Kennedy, A., Reynolds, K., & et al. (2024). Timss 2023 international results in mathematics and science. *IEA TIMMS & PIRLS*.

Index