Using Biographies to Teach the Nature of Science and Science Content

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Abstract: Science content and concepts concerning the nature of science (NOS) are two key aspects of scientific literacy, the promotion of which is the primary goal of general science education. However, the NOS, which acknowledges the human and societal aspects of science, is often neglected in favor of the content teachers are required to cover. The result is what Duschl (1990) calls "final-form" science, which presents science as a string of decontextualized facts and as settled knowledge. This common form of instruction leads students to develop misconceptions about NOS concepts by obscuring how scientific knowledge is developed by people. This essay argues that biographies of scientists, when carefully selected and implemented within the classroom, can be used to effectively teach both science content and NOS concepts, without requiring additional instruction time.

Introduction

> *Alice is a fifth grader in a science classroom. Her teacher asks everyone to open the textbook and read about the Earth's rotation around the sun while answering questions on a worksheet. Alice reads through the information and hastily scribbles answers. None of the questions require her to do anything beyond copying a few words from the book, nor do they ask her to consider the origin of the scientific knowledge she is collecting. She puts almost no thought into the task at hand. The next day, Alice receives her grade on the worksheet – an A. She glances at the result, exclaims, "Yea! I got an A!" and drops the worksheet into the recycling bin. "Alice," admonishes her teacher, "You need that worksheet to study for the test! Put it in your homework folder." Alice complies. After memorizing the facts and acing the test, Alice asks the teacher if she may throw away her pile of worksheets. "The test is over, so you don't need them anymore," the teacher replies. Into the wastebasket goes the entire astronomy unit. Alice's recollection of astronomy facts is not far behind.*

Although the above scenario may be familiar to many teachers and students of science, it is an example of what Duschl (1990) calls, "final-form science," a method of science instruction which reduces science to a long list of facts to be memorized and experiments used to validate the facts being taught (Wang & Marsh, 2002). Final-form science takes the curiosity, creativity, frustration, and inspiration that comprise human scientific processes and sucks them straight out, leaving a bare skeleton of facts. Students are left to assume that these "facts" are certain and absolute, plucked straight from nature as if by magic. Not so. Every piece of recorded scientific knowledge has been developed by people through years of observation, experimentation, and interpretation. Just as importantly, established "facts" are subject to change, as new evidence becomes available; therefore just telling students what the "facts" are does not give them a comprehensive understanding science and how it works.

What final-form science lacks is instruction in the nature of science (NOS). Although different educational organizations including the American Association for the Advancement of Science (AAAS) (2010) and the National Science Teachers Association (NSTA) (2013) have varying definitions of what the NOS is, they generally agree on its main ideas and that it should be taught. The NOS is comprised of concepts which define scientific knowledge and describe how scientific research is conducted. Within their respective definitions of the NOS the AAAS (2010) and NSTA (2013) agree that scientific knowledge is tentative yet reliable, based on empirical evidence, and constructed through a variety of methods by people working within diverse social and cultural contexts.

Traditional, final-form science teaching may seem harmless, but requiring students to memorize information while neglecting to teach NOS concepts has dangerous implications for society. When the public lacks a firm understanding of the NOS and scientific knowledge, they lack the scientific literacy necessary to make informed choices (Clough, 2011). For example, misconceptions about vaccines and climate change can lead to serious public health and environmental consequences if too many people decline to vaccinate their children or reject policies designed to protect the environment. By neglecting to teach NOS concepts in the classroom, teachers set the stage for misinformed policy and funding decisions (McComas, Almazroa, & Clough 1998), and they ignore the people who worked to develop the knowledge we have today, thereby dehumanizing and decontextualizing science.

> *Imagine that instead of reading from a textbook, Alice reads a biography of Galileo Galilei. The biography explains how Galileo was intrigued by a device invented by a Dutchman which made it possible to see things far away; how he shaped glass lenses to improve upon the original telescope design; how he studied the movement of planets and moons through his telescope; how he took into account Copernicus' earlier work; how he used the data he collected to develop his own explanations; and how he published his findings in support of the idea that the earth revolves around the sun. The biography goes on to describe how Galileo was accused of heresy by the Catholic Church, threatened with torture, and imprisoned for the rest of his life for sharing what he had learned. Alice answers questions about what Galileo learned, how he made observations and developed conclusions based on data, how his findings affect people today, and why he persisted in his pursuit of knowledge despite setbacks and societal pressure.*

This text is far better suited to helping students learn about the NOS. By placing astronomy content within the context of how it was developed – the tools used to gather data (the telescope), the other scientists who influenced the subject and course of research (the Dutchman and Copernicus); the processes involved in the construction of knowledge from data (years of recording observations and constructing explanations); the societal influences upon research and dissemination of knowledge (the role of the Church); and the scientist's personal drive that led him to forge ahead into the unknown (Galileo's curiosity) – the biography of Galileo gives Alice a much more comprehensive and authentic understanding of what people know about the natural world and how they have come to know it. It encompasses several essential NOS concept, all by simply discussing the human aspects of scientific research. These NOS concepts include the understanding that science is a human and social activity, that scientists creatively develop knowledge

to explain data, that science is affected by societal and cultural contexts, and that scientists' knowledge of the world can change based on new evidence. This essay will provide evidence to support the argument that biographical narratives about advancements in science, when carefully selected and applied, can be used to teach students essential NOS concepts by humanizing science, while actually enhancing science content learning.

Using Biographies to Teach NOS

Research indicates that biographies can be used to teach NOS concepts and science content, particularly when NOS concepts are presented explicitly. One strategy of integrating biographies into science instruction is the interactive historical vignette (IHV), proposed by Wandersee and Roach (2005). An IHV is a brief 10 to 15-minute "slice" of history presented in skit form by students. Each vignette focuses on one NOS concept and includes a dialogue between scientists researching a particular phenomenon. Prior to the end of each vignette, students are asked to predict what the scientists will do next. Finally, the teacher leads students in a discussion of the NOS concept featured in the IHV, in terms of its relationship to science today. Recent research on a variation of the IHV format conducted by Nur and Fitnat (2015) found that IHVs can be successfully implemented using an explicit-reflective approach to teach students NOS concepts at the high school level. This approach involves explicit instruction in NOS concepts followed by questions intended to allow students to reflect upon the NOS. As part of the study, which included 17 eleventh-graders, researchers administered a survey to assess students' understanding of seven key NOS concepts both prior to and after students read two different IHVs. The information collected through the survey was used to assess students' NOS knowledge as either naïve, transitional, or informed. Before students read the IHVs, most students' NOS understanding was assessed as naïve, but after students read the IHVs, only one student tested as naïve, and the majority of students (13) tested as informed. Of the seven NOS concepts targeted in the study, students' understanding of the tentative NOS improved most significantly, although students improved in all seven areas. The researchers concluded that combining information about real scientists with questioning and explicit NOS instruction increases students' understanding of the NOS.

Clough (2011) reached a similar conclusion after creating 30 historical short stories as part of a project partially funded by the National Science Foundation. The stories, written by a team including a science historian, science professors, and a reading specialist, were created in order to "humanize science, accurately and effectively teach NOS ideas, improve science literacy and entice more individuals to consider science careers" (p. 705). The stories incorporated explanations of how historical and contemporary understandings of scientific knowledge are related, sidebars which explicitly pointed out NOS concepts, and questions to help students reflect on NOS concepts. One such story, "Personalities and Pride: Understanding the Origin of the Elements," describes how multiple scientists worked to develop an understanding of how elements form (Williams, Kruse, Clough, Stanley, & Kerton, n.d.). The story begins with a scene in a laboratory, which gives students a view of the human nature of scientific research. Later in the story, the following question is

posed: "How might science be different if scientists did not work together, debate each other, and use ideas that are already accepted?" This is one of four text-to-NOS concept links explicitly made within this particular story. Asking students to answer questions relating to the NOS within the narrative requires them to think about and formulate their understanding of the concept in their own words, which may account for the success of this method.

In a study using the stories described above, Vanderlinden (2007) found that post-secondary geology students who read the stories showed a statistically significant improvement in their understanding of NOS concepts compared to students who were not exposed to the stories. However, an unexpected outcome of the study was that students remained naïve in their view of the tentative nature of science, viewing past scientific knowledge as flawed and current scientific knowledge as concrete fact. This misconception may require more contemporary biographical examples or explicit instruction to dislodge. The study also showed that neither group of students showed any meaningful difference in their mastery of the scientific concepts taught, although it is notable that students' content learning was not negatively impacted by the stories, and there was an overall benefit for students who read the stories.

Using Biographies to Teach Science Content

Other studies have demonstrated the efficacy of using biographical texts to improve students' grasp of science content. A study of 209 seventh and eighth graders found that students who read specially designed "scientific discovery narratives" about Galileo and Marie Curie learned and retained more science content than students who read expository texts containing the same conceptual information, without biographical elements (Arya & Maul, 2012). Students with less prior knowledge and students from low-income backgrounds were found to benefit more from the biographical texts than students with some prior knowledge and students who came from higher socio-economic statuses.

Another study of ninth and tenth grade students examined the effects of portraying scientists as people who struggle with their work or personal lives (Lin-Siegler, Ahn, Chen, Fang, & Luna-Lucero, 2016). Each student read one of three types of biographies, including biographies in which the scientists struggled with their research, biographies in which scientists struggled in their personal lives, and biographies in which scientists did not struggle, but were instead portrayed as highly accomplished individuals. Students who read the "struggle stories" showed greater improvement in their science content learning as measured by classroom grades, regardless of whether the struggle was personal or academic, compared with students who read the biographies which portrayed scientists as flawless. Also, students who learned about scientists' academic or personal struggles reported that they felt "connected to" the scientists. As Lin-Siegler et al. (2016) wrote, "The message that even successful scientists experience failures prior to their achievements may help students interpret their difficulties in science classes as normal occurrences rather than a reflection of their lack of intelligence or talent for science" (p. 323). The results of this study suggest that by presenting the failures and struggles scientists face, biographies humanize scientists, thereby motivating students to persevere in

the face of difficulties. In turn, this leads to improved learning outcomes in science. Below is a list of tips for implimenting science biographies.

- Ask NOS-related questions as students read. Have students predict what the scientist will do.
- Explicitly draw students' attention to NOS concepts exemplified in the biography.
- Explicitly point out professional, personal, and societal struggles faced by scientists, as well as their reasons for persevering.
- Engage students in skits based on scientists' methods and findings. Students can write and perform their own skits based on carefully-selected biographies.

Selecting Effective Biographies

Although research has shown that specially-designed biographies of scientists can be used to teach the NOS and science content, with the potential to motivate students through their portrayal of scientists as flawed human beings, not all biographies are well suited to these tasks, and some can even reinforce misconceptions about NOS concepts (Allchin 2003). Therefore, teachers need to be careful when selecting biographies for the classroom. Biographies within textbooks typically eliminate any mention of scientists' failures and primarily discuss their successes (Lin-Siegler et al., 2016). In the process of trying to simplify biographical information and fit the scientific process to a narrative form, many writers distort events, exaggerate the accomplishments of individual scientists, and neglect the actual work and processes that go into scientific research (Allchin, 2003). This leads to what Allchin calls "myth-conceptions" (p. 341), which elevate individual scientists to "superhuman characters" (p. 342) who independently come to great realizations about science in seemingly predestined flashes of inspiration. Errors are erased, the time-consuming aspects of scientific processes are forgotten, and the creative interpretation of data is reduced to a single "aha!" moment (p. 345). Narrative devices may serve to make stories more engaging, but they often do not contribute to an accurate understanding of the NOS.

Dagher and Ford (2005) conducted a study of widely available historical and contemporary biographies of scientists for children and found that the twelve selected biographies focusing on eleven different scientists did not adequately describe the process of data interpretation. The researchers also found that biographies of contemporary scientists did a better job of describing the methods and tools involved in scientific processes than did the historical biographies. In light of these observations, when selecting biographical texts for the science classroom, teachers need to watch out for superhuman traits, for the absence of error, for science being conducted in isolation from other people, and for the oversimplification of scientific processes. Below is a list of characteristics teachers should look for when selecting effective science biographies.

- The scientist is described as a flawed human being – not as a superhuman character.
- The scientist's work is not portrayed as simple, straightforward, quick, or predestined. Errors made by the scientist are included.
- The scientific process is described, including some indication of how the scientist creatively developed explanations from the available data.
- The scientist's struggle and perseverance are included.
- Descriptions of the scientist's personal and societal hurdles (e.g. growing up in poverty, having to flee their country, not being allowed into academia due to gender) may be included.
- The scientist's involvement with and consideration for other scientists and societal norms is evident.

Conclusion

Research indicates that biographical narratives focusing on advancements in scientific knowledge can help students connect to science on a human level, learn science content, and develop a better understanding of NOS concepts. Evidence also shows that biographies may increase student motivation. That said, how those biographies are written and presented within the classroom plays a deciding role in their effectiveness, and there is still much potential for further study into the best ways to teach with biographies. In light of the research described above, there are steps teachers can take to productively use biographies in their classrooms. Teachers need to select biographies that present a realistic view of scientists, including their struggles and how they work within different societal contexts. They also need to explicitly explain the NOS concepts exemplified within biographical narratives and ask students follow-up questions about these concepts. When teachers follow these key guidelines for the selection and use of biographies in the science classroom, they can breathe life back into a decontextualized skeleton of facts, and help to nurture a more scientifically literate society.

References

Allchin, D. (2003). Scientific myth-conceptions. *Science Education, 87*(3), 329-351.

American Association for the Advancement of Science. (2010). *Exploring the nature of science: Using the Atlas of Science Literacy and otehr eudacation resources from AAAS Project 2061.* Washington, D.C.: Author. Retrieved from: http://www.project2061.org/publications/guides/science.pdf

Arya, D. J. & Maul, A. (2012). The role of the scientific discovery narrative in middle school science education: An experimental study. *Journal of Educational Psychology, 104*(4), 1022-1032.

Clough, M. P. (2011). The story behind the science: Bringing science and scientists to life in post-secondary science education. *Science & Education, 20*, 701-717.

Dagher, Z. R. & Ford, D. J. (2005). How are scientists portrayed in children's science biographies? *Science & Education, 14*(3-5), 377-393.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development*. New York: Teacher College Press.

Lin-Siegler, X., Ahn, J. N., Jondou, C., Fang, F. A., & Luna-Lucero, M. (2016). Even Einstein struggled: Effects of learning about great scientists' struggles on high school students' motivation to learn science. *Journal of Educational Psychology, 108*(3), 314-328.

McComas, W. F., Almazroa, H., & Clough, M. P. (1998). The nature of science in science education: An introduction. *Science & Education, 7*(6), 511-532.

National Science Teachers Association (NSTA). (2013). Position statement: Nature of science. Retrieved from: www.nsta.org/about/ positions/natureofscience.aspx.

Nur, E. M. & Fitnat, K. (2015). Explicit-reflective teaching nature of science as embedded within the science topic: Interactive historical vignettes technique. *Journal of Education and Training Studies, 3*(6), 40-49.

Vanderlinden, D. W. (2007). Teaching the content and context of science: The effect of using historical narratives to teach the nature of science and science content in an undergraduate introductory geology course. (Unpublished doctoral dissertation). Iowa State University, Ames.

Wandersee, J. H. & Roach, L. M. (2005). Interactive historical vignettes. In J. J. Mintzes, J. H. Wandersee, & J. D. Novak (Eds.), *Teaching science for understanding: A human constructivist view* (pp. 281-306). Cambridge, MA: Academic Press.

Wang, H. A. & Marsh, D. D. (2002). Science instruction with a humanistic twist: Teachers' perception and practice in using the history of science in their classrooms. *Science and Education, 11*(2), 169-189.

Williams, B., Kruse, J. W., Clough, M. P., Stanley, M. & Kerton, C. (n.d.). Personalities and pride: Understanding the origins of elements. Retrieved from https://www.storybehindthescience.org/pdf/nucleosynthesis.pdf.

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