Teaching Nature of Science Through the High School Production of the Theatre Play *Life of Galileo*, by Bertolt Brecht

Dimitris Timpilis
dimitris.timpilis@miami.edu
Ph.D. Student in STEM Education
Department of Teaching and Learning
School of Education and Human Development
University of Miami
5202 University Drive
Coral Gables, FL 33146

Descriptors: Action Research, Instructional Design

Abstract

Many scholars, educational institutions, and governmental bodies, including the National Research Council, consider science literacy and the Nature of Science understanding fundamental goals of K–12 STEM education. However, there is little research exploring the enhancement of Nature of Science understanding through theatre productions related to the history of science. This action research design proposal suggests that the adaptation and production of *Life of Galileo* by Bertolt Brecht could improve high school students' online research skills, enhance students' understanding of research, the scientific method, and the criteria that differentiate scientific from non-scientific theories. All the above improvements of skills could lead to the enhancement of students' Nature of Science understanding.

Introduction

The Research Question

Could the high school production of the theatre play *Life of Galileo* by Bertolt Brecht enhance the students' Nature of Science understanding?

Nature of Science in K-12 STEM Education

The arguments for incorporating History and Philosophy of Science (HPS) (Klopfer & Cooley, 1963) in STEM (Science, Technology, Engineering, & Mathematics) education, the calls for science literacy (Rutherford & Ahlgren, 1989), and proposals for ways of implementing the teaching of Nature of Science (NOS) understanding (Lederman & Lederman, 2004) in educational institutions are not new. NOS is the general term defining the scientific enterprise that incorporates both HPS and science literacy. NOS is a fertile hybrid arena that combines elements of various social science studies. NOS incorporates history, sociology, and philosophy of science, coupled with cognitive science research, such as psychology, into a rich explanation

of what science is, how it operates, how scientists function as a social community, and how society itself both guides and reacts to the scientific goal (McComas, 1998, p. 4).

Rutherford (2001), Teixeira, Greca, & Freire (2009), Garik & Benétreau-Dupin (2014), Matthews (2014, 2017, 2018), Michel & Neumann (2016), and other scholars argue that HPS can contribute to contemporary U.S. Science teaching for K-16 education and advocate the inclusion of HPS in their science syllabi (Matthews, 2014). Garik & Benétreau-Dupin (2014) argue that it is of high importance that students recognize that argumentation, criticism, and analysis are fundamental to science and that students should be educated to value science as part of our culture. Additionally, many scholars claim that the inclusion of NOS in STEM curricula would improve the content learning of students (McComas, 1998; Rutherford, 2001; Dass, 2005; Teixeira et al., 2009; Abd-El-Khalick, 2012; Garik & Benétreau-Dupin, 2014; Matthews, 2014; Michel & Neumann, 2016; Pellegrino, 2016; Gandolfi, 2019).

According to Matthews (2014), many governmental and educational bodies in the past few decades have proposed the inclusion of HPS or NOS to their science syllabi, among which is the U.S. National Research Council (NRC), with its Next Generation Science Standards (NGSS) (National Research Council, 2013). Matthews (2014) argues that incorporating HPS into STEM curricula "has a significant contribution to make to improving science teaching and learning and, consequently, personal and social flourishing." (p. 14).

The justification of the NRC (2013) for integrating NOS into STEM education is that people need to know and understand the world around them. Moreover, humans need to modify their world by using technology to match what they understand or want. In certain situations, the need to know emerges from fulfilling essential needs in the face of possible risk. It is often a natural curiosity, and in other instances, it promises a better, more comfortable existence. Science is the pursuit of natural world explanations, while technology and engineering are the means to fulfill human needs, intellectual interests, and ambitions. Another consistent characteristic of scientific knowledge across disciplines is that scientific knowledge itself is subject to revision in the light of new evidence (p. 96). A scientifically literate person who can appreciate scientific knowledge's essence is a fundamental aim of K–12 science education.

Garik and Benétreau-Dupin (2014) drew the critical conclusion that science education must be integrated into a liberal arts education to prepare students to be equal participants in a participatory democracy. "Science teachers alone should not be expected to prepare students to be scientifically literate, and a modern curriculum that is organized through the humanities would be needed to educate students for scientific literacy." (p. 1853).

This action research design's suggested learning process considers and integrates all the NOS factors of McComas' (1998) description and follows the NGSS on NOS (NGSS, NRC, 2013). The resources and tools suggested for this project to improve NOS understanding are debating and argumentation, online research, interdisciplinarity, and using art in STEM education, in this case, the performing arts, and more specifically, theatre.

Using Theatre to Enhance Students' Nature of Science Understanding

The Drama-based pedagogy (DBP) is well researched and applied (Lee et al., 2015). It is a collection of drama-based teaching and learning strategies to facilitate learning in non-drama and drama-specific content through an embodied process-oriented approach to learning. Nevertheless, in DBP, the non-drama content focuses mainly on reading comprehension, social

and emotional skills, or other non-scientific areas. Also, DBP interventions are usually limited in their scope and duration.

There are cases where theatre is implemented for teaching the philosophy of science (Toonders, Verhoeff, & Zwart, 2016)), popularizing the theory of evolution in a science museum setting (Peleg & Baram-Tsabari, 2016), or even dramatize original research and present it to elementary school students (Burgin, Alonzo, & Hill, 2016). Nevertheless, researchers have highlighted the limited use of drama in education. And while according to Toonders, Verhoeff, & Zwart (2016), "Drama is a relatively unexplored tool in academic science education," Braund (2015) goes so far as to ask the question of whether drama and learning science is "an empty space."

Theatre has indeed been used to support science teaching (Giliberti et al., 2019; Abed, 2016; Kerby et al., 2010; Peleg & Baram-Tsabari, 2011; Yoon, 2006) or history of science (Jansson & Aksela, 2013), but to a minimal degree. Some researchers have recently employed theatre to expand student understanding of NOS (Burke, Wessels, & McAvella, 2018; Burke, McAvella, & Wessels, 2020) or even train new science teachers on the NOS (Melo & Bächtold, 2018). However, they were limited both in time and their scope.

Adapting and Producing the Play *Life of Galileo*, by Bertolt Brecht

This action research design is about the adaptation and production of the play *Life of Galileo* by Bertolt Brecht in the context of an elective course (e.g., Theatre I to Theatre IV Honors) offered to all high school students of a school in the Miami-Dade area in Florida. The book used for the production will be *Life of Galileo (Student Edition)* by Bertolt Brecht (Brecht, 2020). The play is about the Italian natural philosopher's career whom the Roman Catholic Church tried for the proclamation of his scientific discoveries. The play's primary theme is the conflict between science and dogmatism. The students' understanding of the experiment, the scientific method, and the criteria that differentiate scientific from non-scientific theories could be expanded through different stages of the play's production. It is essential that students acknowledge that debating through valid arguments, criticism, and analysis, are fundamental operations in science and learn to value science as part of our shared human culture. The students will be evaluated through the readings, online research, rehearsals for the play's production, and their replies to an open-ended questionnaire and interview administered three times during the school year.

Lastly, this design will invite teachers from other disciplines to get involved and facilitate the students learning of the NOS, e.g., educators that teach language, literature, history, philosophy, social sciences, and STEM subjects, e.g., physics, mathematics, and biology.

The Use of Online Research

This research proposal intends to ask students, throughout all the stages of the play's production, to conduct online research in small teams about the topic in question and decipher whether the sources they find are reliable scientific sources or not. Following the online research, each team could be asked to present and explain the topic to the rest of the class. In other instances, the whole class could be split into two parts and debate, using their argumentation skills, taking opposing views on the given topic. The topics could be assigned by the theatre teacher or emerge throughout the production processes of the play. The topics that emerge could

be specific to the historical events described in the play, for example, Galileo's life, the telescope, the gravitational theories, e.t.c., or broader topics related to science. These broader topics could be, for example, the history and philosophy of science, the scientific method, and the history, the physics, or the mathematics of gravitational theories from Aristotle to Einstein.

The Interdisciplinarity of the Project

An essential aspect of the scientific endeavor is its interdisciplinary and collaborative nature. Understanding NOS includes the understanding that scientific inquiry is a process where a multitude of disciplines are contributing through the ages in the effort of the human species to understand nature and human's place in it. Although the play is concentrated on Galileo, it is clear that people from other crafts and disciplines, for example, people like Giordano Bruno, Copernicus, a lens grinder, the inventor of the telescope, mathematicians, astronomers, philosophers, and other scholars, appear or are mentioned in the play (Brecht, 2020). Through all the production processes of the play, students could realize how the various disciplines are included, each of them offering their perspective and knowledge, providing a more multifaceted understanding of the scientific inquiry.

Teachers from other disciplines will be invited as guest speakers to facilitate the conversation related to their field of expertise. The rationale for this is to highlight the interdisciplinarity of scientific inquiry and the collaboration of different scientific disciplines in scientific research.

A language teacher could be a valuable resource as she can explain unknown words or scientific terms and help with the play's language analysis, which will also accommodate diverse learners. The students analyzing the language used in the play and the words and expressions used in the 17th century (and are not used anymore) could significantly improve their understanding of the language of the play, the innuendos, and the nuances that would be missed without the language teacher's input. The engagement of the English teacher might be essential for the first stage of the readings of the play.

A literature teacher could work with the theatre teacher at the play's analysis stage and the conversation about playwright Bertolt Brecht and his ideas. Furthermore, a literature teacher could help the theatre teacher explain the characteristics of Brecht's Epic Theatre, a theatrical movement of the early 20th century based on theories and practices responding to the era's political climate, leading to the creation of new political dramas.

A history teacher will be needed for both the history of the Copernican revolution and the scientific revolution, together with their socio-cultural aspects. The theatre teacher has a master's degree in history and philosophy of science and technology, and together with the history teacher, could navigate the students through the historical events that lead to Galileo's discoveries and to the conflict with the Catholic Church, as well as the events that followed Galileo's era. Students' understanding of the history of science could enhance their NOS understanding.

A philosophy teacher, in collaboration with the theatre teacher, will define what philosophy of science is and shed light on the philosophical aspects not only of the scientific revolution and the scientific method but also of the theological positions in opposition to the scientific conclusions of Galileo about the revolution of the Earth around the Sun.

A physics teacher could offer more detailed explanations and insights into Galileo's theory from a scientific perspective. The physics teacher could construct two experiments. The

first could be about measuring the acceleration of gravity using only a measuring tape to measure the altitude from which a ball is let fall and a stopwatch to measure the time it takes the ball to reach the floor. For the second experiment, the students could also calculate the acceleration of gravity using, this time, a swinging pendulum. The students could be informed that in all measurements, there are errors introduced. So, after repeating the experiments several times, the students will be taught how to use linear regression to find an approximation of the acceleration of gravity. A conversation could come after the experiments where the team will discuss the processes of physicists, the unavoidable errors introduced in measurement, and the reasons for recreating and repeating experiments.

The mathematics teacher will work together with the theatre teacher (who also has a bachelor's degree in mathematics and teaches mathematics at the school) concerning the mathematics involved in Galileo's theory. Furthermore, a discussion could follow on the nature of mathematics as a model for physics and other sciences. To increase NOS understanding and accurately describe the scientific method, students need to understand the importance that the mathematical models of the natural phenomena in question play in creating a hypothesis or, eventually, a theory in physics.

The biology teacher could also be proved essential because Galileo lived through two Plague outbreaks during his lifetime. A Plague outbreak takes place in one of the play's scenes that affects the characters' actions. In addition, given the COVID-19 pandemic and the requirement that students wear masks, an understanding of the biology aspect of pandemics is crucial not only for the analysis of the play and the understanding of the current situation but also for further deepening the NOS understanding of the students.

The presence and interaction of all the teachers from different disciplines working together to help students understand the multitude of ways available to explore the nature of the scientific endeavor could result in students' deepening of understanding of NOS.

Assessment Instruments for NOS Understanding

There are multiple assessment instruments for evaluating students' NOS understanding that have been proposed, administered, researched, and validated (Lederman et al., 2002; 2004; 2014; 2017, Lovelace & Brickman, 2013). Lederman et al. (2017) describe a plethora of NOS assessment instruments developed to assess students from 1954 to 2006 (Lederman et al., 2017, pp. 981-986). VNOS differs from typical paper and pencil instruments because of its open-ended nature. The results of their various studies and the follow-up interviews supported a high confidence level about the validity of the VNOS for assessing NOS understanding (p. 517). A historical review of the VNOS questionnaire and interview script can be found in the paper by Ayala-Villamil & García-Martínez (2021).

Lederman et al.'s paper (2017) is focused on evaluating the development of the open-ended instrument, *Views of NOS Questionnaire (VNOS)*. The authors find evidence regarding VNOS validity for the range of the NOS aspects it aims to assess. Lederman et al. claim that establishing an instrument's validity is always an ongoing process. The best the researchers can do is provide evidence of an instrument's efficacy in measuring what it is designed to measure. The results of their various studies and the follow-up interviews supported a high confidence level about the validity of the VNOS instrument for assessing NOS understanding.

For this action research project, we plan to use the *VNOS-Form C* instrument (Lederman et al., 2002, p. 509), adapting and improving it to assess students' understanding of NOS before

the beginning of the classes, during the online research and rehearsals, and after the performances.

The Timeframe of the Design Proposal

First Grading Period

Part of the classes at the beginning of the school year is the administration of the *VNOS Form C Open-ended Questionnaire and Interview Script* (Lederman, 2002, p. 509). The plan for the improvisations, theatrical games, and team-building activities is the themes to be taken from historical debates within the scientific community and between scientists and philosophers, religion advocates, or proponents of other disciplines of inquiry. Usually, during the first grading period, the students read the play, analyze the plot and the characters, and improvise on specific characters for the casting process. The students will be asked to conduct online research in teams about topics related to their characters, the era, the themes introduced in the play, and unknown scientific terms. Then they could be asked to explain the researched topic to the rest of the team or engage in a debate. The language, the physics, and the biology teacher could come as guests during this first grading period. All the guests will present their topics and then, with the help and the interventions of the theatre teacher will lead a discussion with the students.

Second Grading Period

By the beginning of the second grading period, the casting will be finalized. At this point, the students usually present parts of their scenes and explore their characters by going more in-depth in understanding their intentions, the relations with the other characters, and the plot. The students will be asked to research online and discuss what natural philosophy, the experiment, and natural philosophy's methods were in Galileo's era. The literature teacher could come as a guest to discuss Brecht and *Epic Theatre* with the students. The theatre teacher could present and discuss with the students the history of science from Mesopotamia (3000 BCE) to Italy (1600 CE) and the history of optics in art and science, the camera obscura, and the telescope. The mathematics teacher could present the mathematics of Galileo's theory and the process of creating a mathematical model of a natural phenomenon. The history teacher could present to the students the history of the Catholic Church and the Inquisition. The *VNOS Form C Open-ended Questionnaire* and the interviews are planned to be administered again at the end of this second grading period.

Third Grading Period

During the third grading period, the students learn their lines, improvise their scenes staying in character, and have more detailed conversations about their characters. During this period, it is suggested to discuss how science and other inquiry disciplines affect and form different opinions, psychological traits, and characters and how society affects the object of scientific inquiry and its direction. How cognitive science research is conducted, and how science is different from art. The philosophy and the social studies teachers could be invited during this grading period. These two teachers and the theatre teacher could suggest topics for students' continuing online research, discussion, and debate.

Fourth Grading Period

The fourth grading period is devoted to rehearsing whole acts, the dress rehearsals, and the performances. More elaborate conversations on Galileo's scientific theory and the Catholic Church's beliefs and why they oppose each other are proposed to happen from a philosophical point of view. Themes that could be discussed are the differences between scientific knowledge, beliefs, and opinions and how the same scientific data can have different interpretations within the scientific community. The conversations for the last grading period are suggested to be about NOS, HPS, and Science literacy. This last grading period is the time for the students to self-reflect on what they have learned about what science is and its relationship with society. The *VNOS Form C Open-ended Questionnaire* and the interviews are proposed to be administered once more before the end of the fourth grading period.

Coda

The author understands the theatre team as a community that is building its knowledge collectively. The theatre teacher is a part of that community. Student questions about different themes, topics, or terms that could emerge at any point of the production process of the play could change the suggested timeframe of this proposal. Following a predetermined schedule independently of the flow, the process, and the level of student understanding defies the purpose and the iterative nature of action research. Action research, both as a philosophy and methodology of research, is a process that leads to transformative change through the iterative operation of taking action and doing research, linked and becoming a whole through critical reflection (Stringer, 2014).

Data Collection and Methodology

Throughout the school year, the qualitative data intended to be collected are observations and field notes, videos of all the lessons and the interviews, three answered *VNOS Form C Open-ended Questionnaires* from each participant student, and the interviews of the students. The assessment instrument for measuring the students' NOS understanding will be the *Views of Nature of Science - Form C Questionnaire and Interview Script*, which can be found in *Views of Nature of Science Questionnaire: Towards Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science* (Lederman et al., 2002). At the end of the school year, all the observation and field notes, the videos, the three answered questionnaires per participating student, and the transcripts of their follow-up interviews will be put together for the qualitative data analysis that will follow. The answers to the questionnaires and the transcribed interview texts will be examined and interpreted to understand what they represent. This coding process of labeling and organizing the qualitative data will identify different themes and their relationships.

Views of Nature of Science - Form C Questionnaire and Interview Script

The *Views of Nature of Science - Form C Questionnaire and Interview Script* (Lederman et al., 2002, p. 509) comprises ten open-ended questions. Based on the questionnaire and the students' answers, the researcher will interview the students to ask clarification or follow-up

questions using the ten questions and the students' replies as the interview script. The ten open-ended questions are seen below.

1. What in your view is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge require experiments?
• If yes, explain why. Give an example to defend your position.
• If no, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
• If you believe that scientific theories do not change, explain why. Defend your answer with examples.
• If you believe that scientific theories do change: (a) Explain why theories change? (b) Explained why we
bother to learn scientific theories? Defend your answer with examples.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what the species is?

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, subjects that a huge meteorite hit the Earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

9. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

• If you believe that science reflects social and cultural values, explain why. Defend your answer with
examples.
• If you believe that science is universal, explain why. Defend your answer with examples.

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
• If yes, then at which stages of the investigations you believe scientists use their imagination and creativity:
planning and design, data collection, after data collection? Please explain why scientists use imagination
and creativity. Provide examples if appropriate.
• If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if
appropriate.

Expected Outcomes

A critical reflection could inform and adapt the elective Theatre course based on the implementation of this action research design and its conclusions. Through this process of analysis of learning needs and goals, the end product of this design is suggested to be developing a delivery system to meet the students' needs in successfully enhancing NOS understanding through the school production of theatrical plays relative to the history of science.

References

Abd-El-Khalick, F. (2012). Teaching with and about nature of science, and science teacher knowledge domains. *Science & Education*, *22*(9), 2087-2107. https://doi-org.access.library.miami.edu/10.1007/s11191-012-9520-2

Abed, O. H. (2016). Drama-Based Science Teaching and Its Effect on Students' Understanding of Scientific Concepts and Their Attitudes towards Science Learning. *International education studies*, *9*(10), 163-173.

Ayala-Villamil, L. A., & García-Martínez, Á. (2021). VNOS: A Historical Review of an Instrument on the Nature of Science. *Interdisciplinary Journal of Environmental and Science Education*, *17*(2), e2238.

Braund, M. (2015). Drama and learning science: An empty space? *British Educational Research Journal*, *41*(1), 102-121.

Brecht, B. (2020). *Life of Galileo (Student Edition)*. Methuen Drama.

Burgin, S. R., Alonzo, J., & Hill, V. J. (2016). Dramatizing the Authentic Research of a Local Scientist to Urban Elementary Students Through Professional Theater. *Science & Education*, *25*(9), 1073-1088.

Burke, L. E. C.-A., Wessels, A., & McAvella, A. (2018). Using Theater and Drama to Expose and Expand the Epistemic Insights of Youth Regarding the Nature of Science. *Research*

in Science Education (Australasian Science Education Research Association), *48*(6), 1151-1169.

Burke, L. E. C.-A., Wessels, A., & McAvella, A. (2020). Using Drama to Uncover and Expand Student Understanding of the Nature of Science. *The Science Teacher (National Science Teachers Association)*, *88*(2), 28.

Dass, P. M. (2005). Understanding the Nature of Scientific Enterprise (NOSE) through a discourse with its history: The influence of an undergraduate 'History of Science' Course. *International Journal of Science and Mathematics Education*, *3*(1), 87-115. https://doi-org.access.library.miami.edu/10.1007/s10763-004-3225-1

Gandolfi, H. E. (2019). *Exploring and implementing an intercultural model of history of science to teach about nature of science* (Doctoral dissertation, UCL (University College London).

Garik, P., & Benétreau-Dupin, Y. (2014). Report on a Boston University conference December 7–8, 2012 on How can the history and philosophy of science contribute to contemporary U.S. science teaching? *Science & Education*, *23*(9), 1853-1873.

Giliberti, M., Adorno, D. P., Pizzolato, N., Battaglia, O. R., & Fazio, C. (2019, August). Augmented lectures: benefits of supporting physics teaching with the theatre. In *Journal of Physics: Conference Series* (Vol. *1286*, No. 1, p. 012065). IOP Publishing.

Jansson, J., & Aksela, M. (2013). Science theatre in teaching and popularizing the history of chemistry: The case of a theatrical play on Nobel-laureate A.I. Virtanen. *Lumat: International Journal of Math, Science and Technology Education*, *1*(4), 457-475.

Kerby, H. W., Cantor, J., Weiland, M., Babiarz, C., & Kerby, A. W. (2010). Fusion Science Theater Presents The Amazing Chemical Circus: A New Model of Outreach That Uses Theater To Engage Children in Learning. *Journal of Chemical Education*, *87*(10), 1024-1030.

Klopfer, L., & Cooley, W. (1963). The history of science cases for high schools in the development of student understanding of science and scientists. *Journal of Research in Science Teaching*, *1*(1), 33-47.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Towards valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521.

Lederman, N., & Lederman, J. (2004). Revising instruction to teach nature of science: Modifying activities to enhance students' understanding of science. *The Science Teacher*, *71*(9), 36-39.

Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Meyer, A. A., & Schwartz, R. S. (2014). Meaningful assessment of learners' understandings about scientific inquiry—The views about scientific inquiry (VASI) questionnaire. *Journal of research in science teaching*, *51*(1), 65-83.

Lederman, N. G., Bartos, S. A., & Lederman, J. (2017). The development, use, and interpretation of nature of science assessments. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 971–997). Springer.

Lee, B. K., Patall, E. A., Cawthon, S. W., & Steingut, R. R. (2015). The effect of drama-based pedagogy on preK–16 outcomes: A meta-analysis of research from 1985 to 2012. *Review of Educational Research*, *85*(1), 3-49.

Lovelace, M., & Brickman, P. (2013). Best practices for measuring students' attitudes toward learning science. *CBE—Life Sciences Education*, *12*(4), 606-617.

McComas, W. (Ed.). (1998). *The nature of science in science education: Rationales and strategies.* Kluwer Academic Publishers.
Matthews, M. R. (2014). *Science teaching: the contribution of history and philosophy of science, 20th anniversary revised and expanded edition.* Rutledge.
Matthews, M. R. (2017). *International handbook of research in history, philosophy and science teaching.* Springer.
Matthews, M. R. (Ed.). (2018). *History, philosophy and science teaching: New perspectives.* Springer.
Melo, É., & Bächtold, M. (2018). A Theater-Based Device for Training Teachers on the Nature of Science. *Science & Education*, *27*(9), 963-986.
National Research Council. (2013). *Next generation science standards: for states, by states.* The National Academies Press. https://www.nap.edu/catalog/18290/next-generation-science-standards-for-states-by-states
Peleg, R., & Baram-Tsabari, A. (2011). Atom Surprise: Using Theatre in Primary Science Education. *Journal of Science Education and Technology*, *20*(5), 508-524. http://dx.doi.org/10.1007/s10956-011-9299-y
Peleg, R, & Baram-Tsabari, A. (2016). Understanding Producers' Intentions and Viewers' Learning Outcomes in a Science Museum Theater Play on Evolution. *Research in Science Education*, *46*(5), 715-741.
Pellegrino, J. W. (2016). *21st century science assessment: The Future Is Now.* SRI International.
Rutherford, F.J., & Ahlgren, A. (1989). *Science for all Americans*. Oxford University Press, Inc.
Rutherford, F. J. (2001). Fostering the history of science in American science education. *Science Education and Culture*, 41–52. https://doi.org/10.1007/978-94-010-0730-6_4
Stringer, E. T. (2014). *Action research in education*. Pearson.
Teixeira, E. S., Greca, I. M., & Freire, O. (2009). The history and philosophy of science in physics teaching: A research synthesis of didactic interventions. *Science & Education*, *21*(6), 771–796. https://doi.org/10.1007/s11191-009-9217-3
Toonders, W, Verhoeff, R.P., & Zwart, H.A.E. (2016). Performing the future: On the use of drama in philosophy courses for science students. *Science & Education, 25*(7), 869-895.
Yoon, H. G. (2006, May). The nature of science drama in science education. In *the 9th international conference on public communication of science and technology (PCST-9). Seoul, Korea*.