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Effect of STSE Approach on High School Students' Understanding of Nature of Science

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Abstract
Nature of science (NOS) has been a target of interest for decades. The main goal of this study is to explore the impact of the science, technology, society, environment (STSE) approach on students' understanding of NOS, taking "Galileo's study of free-fall motion" as an example. Participants in this study were 350 students of grade 10 from a public high school in China. The *Student Science Understanding and Scientific Inquiry* (SUSSI) instrument was used in the intervention and control groups to explore the impact on students' NOS. The intervention group ($N=210$) participated in the STSE class, whereas traditional instruction was applied to the control group ($N=140$). Results revealed that there was a significant difference between the two groups, and the learners in the intervention group understood NOS better than the control group. STSE approach is an effective way to enhance students' understanding of NOS. Despite the fact that the implementation is challenging for teachers, it appears that the STSE approach has positive effects on students' understanding of NOS, which offers some reference for physics classroom teaching.

Keywords NOS · High school students · STSE approach · Physics education

Introduction

In the twenty-first century, science and technology have made enormous advances. While the use of scientific knowledge has brought great benefits to mankind, it has also had a negative impact on the society and the environment. Many countries are preparing their citizens for the world of tomorrow by incorporating scientific knowledge into school curricula (Organisation for Economic Co-operation and Development, 2016). Young people should therefore be able to use science to identify and solve problems in the real world. The main goal of science education is to help students develop scientific literacy (Yulianti, 2017). The aim of improving scientific literacy is to enable students to solve everyday problems scientifically, think critically, identify evidence, make informed decisions about the world, master technology, and adapt to changes and developments in the world (Surpless et al., 2014). The Canadian Council of Ministers of Education (CMEC) describes scientific literacy as the ability of students to engage in inquiry, problem solving, and scientific reasoning, as well as the knowledge, skills, and attitudes associated with NOS (CMEC, 2016). In turn, the nature of science (NOS) within it is recognized as a key component of scientific literacy in reform documents around the world (American Association for the Advancement of Science, 1993; NGSS Lead States, 2013). Recent research has recommended that NOS should be part of all science curricula (Lederman & Lederman, 2014; Mesci, 2016; Olson, 2018) and has emphasized the importance of NOS instruction for all students (Akerson et al., 2019; Murphy et al., 2019). The importance is reflected in many recent national curriculum documents from the USA and other countries (Olson, 2018).

Science, Technology, Society, Environment (STSE) approach focuses on curricular and pedagogical issues that address the links between science, technology, society, and the environment. It can be used to enhance students' ability to apply scientific knowledge in order to understand the relationship between what they learn in the classroom and what happens in their everyday lives and to engage in meaningful science learning (Pedretti et al., 2008; Pedretti & Nazir, 2011). In addition, students have the opportunity to practice

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asking scientifically valid questions, designing experiments, exploring, analyzing, and interpreting data in order to find solutions to problems. Students also need to be aware of the social and physical environment through a social science context (Pedretti & Nazir, 2011). STSE education stems from the belief that a connection between students and the real world should be established. Research has shown that helping students understand the essential view of science is an important goal of STSE education (Guo et al., 2021), which should include teaching the nature of science and making students aware of the complex relationships between science and technology, society, and environment. Therefore, the aim of this study was to attempt to determine the impact of STSE approach on the NOS of the 10th students.

Literature Review

STSE Approach

STSE education has been a major goal in science education since the 1970s, and it remains one of the top priorities for science education reforms today (Pedretti & Nazir, 2011). STSE prepares learners for an increasingly technologically driven economy (Akcay & Akcay, 2015; Lau, 2013). STSE is a new form of science-technology-society (STS) approach after adding environment to it. In their work, according to Aikenhead (2005), STSE approach significantly improved students' understanding of social issues, attitudes toward science, and thinking skills. STSE approach helps learners relate science to their daily lives (Kim et al., 2012). Students who intend to continue studying physics in college can also benefit from it (MacLeod, 2013). Yalaki (2016) explored the impact of an optional course on students' competencies in STSE approach. The results showed that students were able to achieve higher competencies in some areas of STSE approach, while having difficulty in other areas. Lau (2013) noted that using STSE approach can improve students' scientific literacy even further in Hong Kong high schools. Collaborative learning-based STSE can increase student motivation in acid–base chemistry classes (Priyambodo et al., 2020). Bar et al. (2016) used STSE approach in teaching electrolysis for high school to introduce the case of electrolysis. The results suggested that all students liked this approach and wanted to continue following the same approach in school. Silva and Neves (2020) argued that students gain more scientific and technical knowledge, and a broader understanding of the environmental and social issues analyzed in the process of realizing these activities. Calado et al. (2015) studied biology textbooks from two different German publishers. Their findings suggested that both books deal with the relationship between science and technology, with one book emphasizing social impacts and the other emphasizing environmental impacts.

STSE approach is a more integrated form of education, guided by the idea of integrating students' understanding of science and technology with their daily life, social and productive experiences, and environmental protection. With the rapid development of science and technology, various social and environmental issues are becoming more prominent, and therefore, environmental issues are beginning to gain importance. STSE approach should include teaching the NOS and making students aware of the complex relationships between science and technology, society, and the environment (Guo et al., 2021). However, today, STS and STSE approaches continue to be used interchangeably. Some countries have adopted this approach in the form of STS, while others have adopted STSE. In China, STSE approach was used in this study. In the Chinese science curriculum, the sub-dimensions on STSE are social science issues, the NOS, sustainable development, the relationship between science and technology, the contribution of science to society, and science and career awareness (Ministry of Education of China, 2017).

NOS

Although there is no single definition of NOS (Lederman & Lederman, 2012), NOS has been defined as the epistemology of science, the role of scientists in scientific research, and the advancement of scientific knowledge (Lederman, 2007). Clough (2006) defines NOS as the understanding of how scientific knowledge is produced, what science is, the fundamentals, the interactions between science and society, and the role of scientists. NOS teaching can be divided into implicit and explicit/reflective pedagogies. Implicit pedagogy refers to embedding the content of the NOS in teaching through scientific inquiry and experimental activities to enhance students' understanding of the NOS in an indirect way. Explicit/reflective approaches refers to interpreting the NOS from multiple perspectives, such as the history and philosophy of science, directly and explicitly educating about the NOS through class discussions and reading related materials. Several experienced teachers also advocate the use of explicit and reflective approaches in NOS teaching and provide empirical support (Rudge & Howe, 2009; Williams & Rudge, 2019). Research has shown that explicit/reflective approaches are more effective than implicit approaches in NOS teaching (Khishfe & Abd-El-Khalick, 2002; Lederman & Stefanich, 2006; Schwartz et al., 2004). This means that students learn more effectively and deeply when the subject matter is presented using multiple modes of representation (Byukusenge et al., 2022). There are several different ways to conduct explicit/reflective approaches in NOS teaching (i.e., argumentation-based, inquiry-based, PCK-based, model-based teaching, etc.) (Develaki, 2019; McDonald & McRobbie, 2012; Mesci, 2020; Schellinger et al., 2019). Explicit/reflective approaches in NOS teaching can be used through activities and discussions with or without embedded science content (Akerson et al., 2019).

Some researchers advocated using the history of science (HOS) for NOS teaching (Matthews, 2012; McComas, 2014), and it can help foster students' interest and positive attitudes toward science, as well as encourage learners to think about their own understanding of scientific concepts and reason similarly to scientists of the past (Solbes & Traver, 2003). HOS episodes provide important context for understanding the abstract scientific concepts; students may otherwise have difficulty in understanding (Dedes & Ravanis, 2009). In addition, many science educators have used replicated historical scientific experiments in science education. The replicating of historical scientific experiments involves three stages: reproducing the apparatus, reproducing the process, and contextualizing the experience (Metz & Stinner, 2007; William & Rudge, 2019). The goal of this approach is to reconstruct the original instrument based on historical information and then use it to conduct experiments as close to the original instrument as possible, in order to understand and appreciate how the original experimental data were collected (Heering, 2006). The method of replicating historical scientific experiments allows students to develop an understanding of the historical, philosophical, cultural, social, technological, and political context of the instrument being replicated (Metz & Stinner, 2007). Replicating historical science experiments provides an important avenue for science learning, and there is empirical evidence that it has a positive impact on learning. The main obstacle is that replicating historical experiments requires professional knowledge, especially at the stage of replicating the experimental process, making measurements, and evaluating the results.

There are many researchers who have elaborated on the NOS ideas that align with many historical and contemporary science education reform documents and standards (Lederman et al., 2002; Khishfe & Abd-El-Khalick, 2002; Clough, 2006; McComas, 2014), mainly including (1) scientific knowledge is tentative; (2) scientific knowledge is based on empirical evidence; (3) scientific knowledge is subjective; (4) science requires imagination and creativity; (5) science is socio-culturally embedded; (6) there is a distinction between observation and inference; (7) there is a distinction between laws and theories of science; and (8) scientific research methods are diverse. To achieve better results in teaching NOS, teachers can help students understand NOS objectives by (1) explicitly including NOS as a cognitive objective; (2) integrating NOS with regular teaching content; (3) creating teaching contexts that adequately elicit NOS questions; (4) asking explicit NOS questions; (5) engaging in discussions around issues related to the nature of science; and (6) both process and outcome reflections.

The Purpose and Research Questions of the Study

The purpose of the study was to investigate the effectiveness of STSE approach in improving students' NOS. The following research questions guided the current study:

1. What is the effect of STSE approach over regular teaching on grade 10 students' NOS views?
2. How does STSE approach impact grade 10 students' views about NOS aspects?

Methods

Research Design

A pretest-posttest control group design was used in this quasi-experimental study. Ten classes ($N = 350$) of grade 10 in a Chinese secondary school were taught the same topic "Galileo's research on the free-fall motion," one class was taught using the STSE approach, and the other class was taught using the regular teaching. Three teachers implemented the STSE approach, and the six classes they taught consist of the intervention group with a total of 210 students. The control group consisted of the two teachers in four classes with a total of 140 students. All five teachers involved in the study taught only two classes. The dependent variable in this study was the change in students' NOS before and after the instructional intervention.

The aim of this study was to investigate the impact of using the STSE approach in the physics curriculum on the NOS for grade 10 students. Quantitative data were collected through a science-based scale. The intervention group was taught activities using the STSE approach, and the control group was taught traditionally. The study lasted a total of 12 weeks: 1 week of pre-test, 10 weeks of implementation, and 1 week of post-test. At the end of the 12 weeks of instruction, the scales used in the pre-test were applied to the post-test, and changes in the nature of science were determined for both groups of students.

A quasi-experimental design with a pre-post-test control group was used in the study. Ten classes ($N = 350$) were taught the same topic "Galileo's study of free-fall motion," and the STSE approach was implemented by three teachers, who taught six classes comprising the intervention group of 210 students. The control group consisted of four classes taught by two teachers with a total of 140 students. All five teachers involved in the study taught only two classes, and the ten classes were parallel classes.

Participants

The research explored in this study involved grade 10 students of Hunan province in central China. The school-related statistics indicated that students in the classes had mixed abilities. All participants and their accompanying persons provided informed consent and ethical approval for the study. These students are all Chinese in grade 10, with an average age of 15 to 16 years old. To ensure that teachers in the intervention and control groups were at the same level, we selected five physics teachers who had all graduated from universities with a degree in physics education and who had more than 15 years of experience in teaching physics.

Materials

It was in grade 8 that physics was introduced in China, "Galileo's study of free-fall motion" for the first semester of the grade 10, chapter 2, "Study of uniform linear motion" content. Free-fall is a common motion, and Galileo's research on free-fall motion is of great significance. The central theme of this teaching is to let students know what free-fall motion is, understand the conditions of formation and the nature of free-fall motion; master the concept of acceleration of gravity and the law of free-fall motion; and be able to use the law of uniform linear motion to solve free-fall problems (Li et al., 2020).

Firstly, Chinese ordinary high school physics textbook through demonstration and experimental investigation, analysis to derive the law of free-fall motion, clears the meaning of gravitational acceleration, so that students have a specific, in-depth understanding of the law of free-fall motion. Secondly, introduce Galileo's research process on free-fall motion and his scientific thinking method, so that students' understanding of free-fall-motion rises to a higher level. The teaching content of "Galileo's research on free-fall motion" is presented in the order of "concept-law-history of physics." The physical concepts, scientific thinking, and scientific research in the history of physics can be used as supporting materials for students to conduct scientific investigations and scientific arguments. "STSE" is the educational concept of linking science, technology, society, and environment. In the module "Galileo's study of free-fall motion," firstly, through the introduction of Galileo, sort out his contribution to modern science, so that students understand and appreciate science and society. Through understanding Galileo's inclined plane experiment and data manuscript, students can know that science. By introducing of Galileo's inclined plane experiment and data presentation, students will learn that science needs to be supported by certain evidence; the corresponding principles of the punctuation timer will be incorporated into the course, to make students understand the mutuality of science and technology; through the study of free-fall motion, the hazards of throwing objects "from a height" will be explained, and the awareness of environmental protection will be penetrated.

Data Collection Tools

Pre- and post-implementation survey instruments were used to assess the impact on the NOS, and these surveys are anonymous. Survey results are used solely for research purposes, and no personally identifiable information about students is disclosed or shared outside of the research team. According to the elaboration of the NOS views, the Student Understanding of Science and Scientific Inquiry (SUSSI) instrument (Liang et al., 2008) was utilized to capture the NOS understanding. SUSSI was chosen for some reasons in this study (Appendix Table 5). Firstly, it was hoped that this study could serve as a pilot for a large-scale quantitative study, so an instrument that is both qualitatively and quantitatively flexible in its use was needed. Secondly, however, the qualitative nature of the SUSSI scale would be equally useful for a small-scale study. Finally, the SUSSI could allow measurement of students' understanding of the NOS without relying on students having extensive writing skills or knowledge of the NOS. A disadvantage of more open-ended instruments (e.g., views of nature of science (VNOS)) is that students must have better writing skills to assess students' understanding of the NOS (Rudge & Howe, 2009). Finally, SUSSI has projects with research questions related to the background of scientists and the influence of culture on science, which is important for students to understand the perspective of the NOS.

The reliability of the modified SUSSI scale for the pre-test and post-test was determined by the Cronbach coefficient alpha test, which was 0.804 and 0.644, respectively, indicating a high degree of alignment between the pre-test and post-test of this scale. However, due to the limited writing skills of the students as well as time constraints and the inapplicability of the analysis method, only part of the Likert scale items of SUSSI were used in this study. The SUSSI contains six dimensions: observation and inference, tentativeness of scientific theories, scientific laws and theories, social and cultural influences on science, imagination and creativity in scientific research, and scientific methodology. None of the tests for these dimensions were included in the instruction of the intervention group.

Procedure

The effect of STSE over conventional approach on 10th grade students' NOS views was investigated in the present study. In both intervention and control groups, SUSSI was administered as pre- and post-tests. In the intervention group, the students were taught with STSE approach on the topic of "Galileo's study of free-fall motion" by the first researcher, while those in the control group were taught with conventional approach on the same topic by the science teacher. STSE and conventional approach were administered as presented in detail in Table 1.

Implementation of the Module in STSE Approach Class

In Table 1, students in the intervention group were taught by the researcher using the STSE approach in the classroom. In session 1, the researcher explicitly asked questions about the NOS aspects and STSE, such as "What is the nature of science?" "Can you list some ideas about the nature of science?" and "Do you understand the relationship between science, technology, society and the environment?" The teacher asked the students to increase their attention to the classroom instruction. The researchers then presented NOS and STSE-related content through a multimedia presentation using visual support. For this study, "Galileo's study of free-fall motion" was chosen as a teaching case. In the lesson plans, students are taught what free fall motion is and understand the conditions and properties of the formation of free fall motion; they are taught the concept of acceleration of gravity and the laws of free fall motion and can apply the laws of uniform linear motion to solve free-fall problems (Li et al., 2020). In addition, a number of activities are included in these lesson plans; for example, a demonstration of an experiment on who falls faster with light and heavy objects; a video on the use of parachutes by astronauts leaving Shenzhou; an introduction to the story of the 3 famous apples that changed the world; and a demonstration of the Newton tube experiment.

In the second and third sessions, the researcher introduces the punctual timer and DISLAB digital lab equipment to investigate the laws of free fall motion in order to increase students' interest in the subject; next, students design experimental protocols one and two based on the equipment under the guidance of the teacher. The students then implemented the protocols and collected data. In addition, during the activities, students are explicitly asked to solve real-life problems based on the STSE approach. Throughout the teaching of the STSE approach, the teacher divides the class into 6-7 groups of 4-5 students each according to the principle of heterogeneous grouping, using the grouping form as a basis to ensure that the members of the group are able to support each other and to select a group leader. The students fill in the grouping form, numbering the students in advance and submitting the form when they are finished. The task of the group leader is to lead the group through the task together, ensuring that the group members all learn and that they are efficient and flexible. Students learn in small groups (4-5 students), discussing learning issues and choosing different approaches. Students need to identify the problem to be solved during this activity, the means by which it should be completed and the way in which it needs to be presented. A reasonable plan is drawn up based on the time required for completion, with each member having a unique task and prioritizing the tasks. In addition, after the students have completed the experiment, representatives are selected from within the group to make a preliminary argument within the group about the data collected. In response to the results of the argumentation, the group presents constructive comments and draws conclusions. Finally, the students debriefed in class.

In lessons 4 and 5, teachers use guiding questions to get students to think about the process of constructing scientific knowledge, e.g., is there a difference between the law of free fall motion and other theories? Why were Aristotle's ideas stretched over 2000 years without being disproved? This leads to the process of Galileo's research into the motion of the free fall. At the same time, the teacher guides students to reflect on their own shortcomings in the inquiry process and to engage in continuous inquiry. And students reflecting on their own shortcomings in the inquiry process can be recorded on A4 paper around the following questions: (1) What went well? (2) How can I improve myself? (3) What did I fall short of in the process? (4) What should we not do again? (5) What did I learn from other members? Finally, the teacher summarized what had been learnt in the lesson and designed an exercise that incorporated STSE educational resources to develop students' awareness of saving resources and protecting the environment while they mastered the basics.

Implementation of the Module in Regular Teaching

In the control group, the science teacher taught the students 5 h of regular teaching on the topic of "Galileo's study of the free-fall motion." During the lesson, the students and the teacher gave examples of these concepts from their everyday lives; for example, a book and a piece of paper falling from the same height at rest; a piece of paper and a small ball of paper of the same mass falling from the same height at rest; placing a piece of paper on top of a book and releasing the book; and the paper at rest to compare the speed of their movements. In addition, the teacher demonstrates experimentally how fast or slow light and heavy objects fall, derives the factors that affect how fast or slow objects fall, and demonstrates the Newton's tube experiment. In addition, the teacher leads a group discussion with the students and presents the experiment in front of the class. However, the control group teachers did not provide students with scaffolding or special clues, nor did they provide students with tools to explore NOS. As a result, the teacher mainly used lectures and questions throughout the course.

Table 1 Administration schedule of STSE and conventional approach

Lesson-stage	Group	Task	STSE	NOS
Lesson 1 Stage 1 (5 min)	Intervention	An introduction to the nature of science and the STSE approach by the teacher		
	Control	To introduce the topic with the game "Students experience the reaction time ruler" and introduce the teaching objectives		
Lesson 1 Stage 2 (35 min)	Intervention	1. To introduce the teaching objectives with the use of parachutes when the astronauts left Shenzhou VI 2. Introducing three stories of famous apples that changed the world 3. Experimental demonstration of the factors affecting the speed of fall of an object; demonstration of the Newton tube experiment	Society	Tentativeness
	Control	1. By the question "Does a heavy object fall faster than a light object?" Prompt students to think 2. Experiment to demonstrate the speed of falling of light and heavy objects and the factors that affect the speed of falling of objects 3. To demonstrate the Newton's tube experiment		
Lesson 2 Stage 1 (25 min)	Intervention	1. To introduce point timers and DISLAB digital lab equipment to investigate the laws of free-fall motion 2. Students design experimental protocols one and two based on the apparatus 3. To implement the program and collect data	Technology	Observation and reasoning; diversity of scientific methodology; empirical
	Control	1. To lead a group discussion and develop an experimental protocol to investigate the properties of free-fall motion 2. To carry out experiments and collect data		
Lesson 2 Stage 2 (15 min)	Intervention	1. A representative from the group is selected to make a preliminary argument within the group about the data collected 2. The group makes constructive comments and draws conclusions about the results of the argument 3. Students present their results	Science	Empirical
	Control	1. Students work on data to draw conclusions 2. Teacher's summary		
Lesson 3 Stage 1 (30 min)	Intervention	1. Teacher uses guiding questions to get students to think about the process of constructing scientific knowledge, leading to Galileo's research into the motion of the free fall 2. Students reflect on their own shortcomings in the inquiry process and engage in continuous inquiry	Science	Theories and laws; socio-cultural embedding
	Control	Teacher uses powerpoint to briefly explain the problems Galileo encountered in his study of the motion of free fall and how they were solved		
Lesson 3 Stage 2 (10 min)	Intervention	Teachers design an exercise and assign homework that incorporates STSE educational resources	Environment	
	Control	Teacher explains exercises and assigns after-class work		

Table 2 The pre-test and post-test results of the SUSSI scale between the control and intervention group

Item	*N*	Group	*M*	*SD*	*F*	*t*	*p*
Pre-test	140	Control	3.44	.22	.063	1.605	.109
	210	Intervention	3.41	.17			
Post-test	140	Control	3.93	.38	30.098	348	< .05
	210	Intervention	4.27	.25			

Data Analysis

To answer the research questions, data collection on the questionnaire will be analyzed for differences between the intervention and control groups. Data were entered into SPSS 23.0 software, and descriptive statistics such as frequencies, percentages, and means were used for the analysis of pre-test and post-test results. Also, potential changes in participants' understanding of the NOS were assessed by paired samples *t*-test.

Results

The results of independent samples *t*-test of the SUSSI scale indicated the participants' understanding of the NOS prior to the implementation of this study. The students' understanding of the NOS in the control and intervention groups before and after the implementation of the study is presented in Table 2.

As can be seen in Table 2, there was no significant difference between the pre-test results of the control and intervention groups ($p > 0.05$), while there was a significant difference between the two groups in the post-test, indicating that students in the intervention group had an improved understanding of the NOS. Comparing the students' understanding of the NOS in the post-intervention, the results of the paired samples *t*-test were significantly different in the dimensions of observation and inference, tentativeness of scientific theories, and imagination and creativity in scientific research, as shown in Table 3.

Table 3 Dimensions of SUSSI scale that improve on the pre- and post-test in the intervention group

Sub-scales	Item	*M*	*SD*	*t*	*p*
Observation and inference	Pre-test	3.48	.72	- 3.05	.045
	Post-test	3.61	.67		
Tentativeness of scientific theories	Pre-test	3.50	.57	- 2.12	.019
	Post-test	3.62	.51		
Imagination and creativity in scientific research	Pre-test	2.16	.92	3.26	< .05
	Post-test	2.52	.84		

Table 4 Dimensions of SUSSI scale that did not improve on the pre- and post-test in the intervention group

Sub-scales	Item	*M*	*SD*	*t*	*p*
Scientific laws and theories	Pre-test	3.37	.56	-1.26	.828
	Post-test	3.38	.55		
Social and cultural influences on science	Pre-test	3.05	.77	-.51	.961
	Post-test	3.06	.74		
Scientific methodology	Pre-test	3.14	.57	.36	.78
	Post-test	3.15	.56		

However, there is no significant improvement in the three dimensions of social and cultural influences on science, scientific laws and theories, and scientific methodology, as shown in Table 4 for the pre-test and post-test.

Discussion and Conclusion

The aim of this study was to investigate the impact of STSE approach on the views of grade 10 students on the NOS. In the intervention group, the topic of "Galileo's study of the free-fall motion" was taught using the STSE approach. The control group was taught the same topic in a traditional way, without teaching about STSE content. We quantitatively analyzed the changes in the NOS views of the students in the intervention and control groups before and after the implementation.

The results showed that there was no significant difference between the students in the intervention and control groups in their understanding of NOS in the pre-test ($p > 0.05$). However, in essence, the students' understanding of NOS was largely inaccurate prior to the intervention. This may be because individuals typically develop an understanding of NOS over time in multiple settings. As many students were unfamiliar with NOS prior to the class, we did not expect them to master its complexity after only one course or one particular teaching method.

In addition, the study determined that there was a significant average difference in NOS perspectives between students who received the STSE approach and those who received regular teaching. Furthermore, STSE instruction improved some aspects of students' NOS (observation and reasoning, tentativeness, imagination, and creativity) more than regular teaching did. Based on these findings, it can be concluded that the differences between groups can be explained by the use of different teaching methods. Engaging in STSE and explicitly highlighting it in the activities may help to improve their NOS perspective. Therefore, teachers should explicitly introduce students to the NOS concept and should give them the opportunity to practice it during their learning process. Similarly, previous research findings suggest that STSE has a positive effect on students' competence, motivation, scientific literacy, learning motivation, and self-regulation (Kim et al., 2012; Yalaki, 2016; Gresch et al., 2015; Lau, 2013; Priyambodo et al., 2020.). Silva et al. (2020) use the STSE approach to allow students to gain greater scientific and technical knowledge and develop a broader understanding of the environmental and social issues analyzed. The STSE approach can be used as an option to improve students' scientific literacy skills. Through this approach of learning, students can apply a variety of relevant scientific concepts and understand the connections between science, environment, technology, and society in relation to environmentally polluting materials (Gresch et al., 2015). In addition, Bar et al. (2016) used the STSE approach in teaching electrolysis in high school to introduce the case of electrolysis. The results showed that all students liked the approach and wanted to continue with it in school. Moreover, the results of this study are consistent with previous research findings on NOS perspectives as described in the literature review chapter (Matthews, 2012; McComas, 2014; Metz & Stinner, 2007; William & Rudge, 2019). The use of explicit and reflective approaches in the teaching of NOS has resulted in positive changes in perceptions of NOS (Williams & Rudge, 2019).

In this study, taking "Galileo's research on the free-fall motion" as an example, the explicit-reflective teaching of the STSE approach, providing a flexible and diverse teaching approach to deepen students' understanding of the NOS, and an effective attempt to improve students' quality. When we analyzed the participants' answers in detail, there were statistically significant differences on tests about the SUSSI scale in the three dimensions of observation and inference, tentativeness, tentativeness of scientific theories, and imagination and creativity in scientific research, for the following reasons. First, in the classroom teaching of the intervention group, students' views were linked to Aristotle's and Galileo's views, which triggered cognitive conflicts and highlighted the tentative nature of the NOS. Second, students design their own Newton's tube experiments and establish the concept of free-fall motion, so that they can understand the NOS in terms of observation and reasoning. Through experimental analysis of the collected data, students can know that science requires the support of certain evidence. By comparing the views of Aristotle and Galileo, students can understand the difference between observation and reasoning; by understanding the case of Galileo and knowing the context of the scientist's time, students can understand the importance of creativity and imagination in the practice of science. Through the classroom teaching, students explored how scientists design so that they can conduct their own inquiry, interpret evidence, and draw conclusions. The result tentatively suggested that STSE approach has a positive impact on the NOS in science teaching. This is because this approach intrinsically draws attention to the critical role of creativity and inquisitiveness in science. In addition, students gain a deeper understanding of the concept and laws of free-fall motion during this learning process.

In summary, teaching with STSE had a significant positive impact on grade 10 students' views of NOS. Students who were taught with STSE showed significant development in some aspects of NOS views. However, there was no significant difference in NOS views on the pre- and post-tests for students taught with regular teaching. In fact, students in the control group may have shown a decrease in NOS because they did not experience any aspect of NOS during regular teaching. This result may be due to the lack of explicit instruction on NOS, a perspective that should be explicitly introduced to students by the teacher. The results of this study may serve as a reference for science teachers, pre-service science teachers, and science teacher educators when teaching NOS. Although there were significant differences between the intervention and control groups in this study, the positive impact of the STSE approach on NOS may not occur with students of lower ability who are more inclined to learn non-systematically through the STSE approach. Students may prefer to use the STSE approach due to the interactive nature of the classroom and the real-life environment, and therefore, their attitudes toward science learning may improve more significantly. The short duration of the course also limits the development of some skills and attitudes. In addition, in future research, students' personal characteristics could be considered so that the relationship between NOS perspectives and personal characteristics can be determined and consider how STSE can enhance students' understanding of other aspects of the NOS.

Appendix

Table 5 Student understanding of science and scientific inquiry scale

Items
1. Scientists may observe the same event differently, as their prior knowledge may affect their observation
2. The development of science will be affected by certain social phenomena and views
3. Scientists will observe the same event, since observation is a fact
4. Scientists may come up with different explanations for the same observations
5. Scientific theories should be constantly tested and amended
6. Scientific theories may be completely replaced by new ones based on new evidence
7. Scientific theories may change because scientists reinterpret existing observations
8. Scientific theories based on accurate experiments will not be changed
9. Scientific theories exist in nature and it is found through scientific investigation
10. Unlike scientific theories, scientific laws do not change
11. Scientific laws are proven theories
12. Scientific theories explain scientific laws
13. Scientific research is not affected by society and culture, as scientists are trained to conduct purely unbiased research
14. Scientists in scientific research are influenced by his life experience, cultural and intellectual background
15. Cultural values and expectations determine how science is carried out and accepted
16. Science is universal and independent of society and culture, so all cultures conduct scientific research in the same way
17. Scientists use their imagination and creativity in collecting data
18. Scientists use data for analysis and interpretation

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Data Availability All data and materials are available from the authors.

Declarations

Ethics Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee.

Consent to Participate The participants were protected by hiding their personal information during the research process. All participants took part in the experiment voluntarily, and they could withdraw from the study at any time.

Conflict of Interest The authors declare no competing interests.

References

Aikenhead, G. S. (2005). Research into STSE science education. *Chemistry Education, 16*(3), 384–397. https://doi.org/10.22201/fq.18708404e.2005.3.66101

Akcay, B., & Akcay, H. (2015). The effectiveness of science-technology-society-environment (STSE) instruction on student understanding of the nature of science and attitudes toward science. *International Journal of Education in Mathematics, Science, and Technology, 3*(1), 37–45. https://doi.org/10.18404/ijemst.50889

Akerson, V.L., Elcan Kaynak, N., & Avsar Erumit, B. (2019) Preparing preservice early childhood teachers to teach nature of science: writing children's books. *Innovations in Science Teacher Education, 4*(1).

American Association for the Advancement of Science (AAAS) (1993). *Benchmarks for science literacy*. New York.

Bar, V., Azaiza, E., Azaiza, D., & Shirtz, A. (2016). Teaching electrolysis using STSE method, multidisciplinary approach. *World Journal of Educational Research, 3*(2), 321–341.

Byukusenge, C., Nsanganwimana, F., & Tarmo, A. P. (2022). Enhancing students' understanding of nerve cells' structures and their symbiotic functioning by using technology-enhanced instruction incorporating virtual labs and animations. *Journal of Science Education and Technology, 32*(1), 13–25. https://doi.org/10.1007/s10956-022-10002-3

Calado, F. M., Scharfenberg, F. J., & Bogner, F. X. (2015). To what extent do biology textbooks contribute to scientific literacy? Criteria for analysing science technology-society-environment issues. *Education Sciences, 5*(4), 255–280.

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education, 15*(5), 463–494. https://doi.org/10.1007/s11191-005-4846-7

CMEC. (2016). *Assessment framework*. Canada.

Dedes, C., & Ravanis, K. (2009). Teaching image formation by extended light sources: The use of a model derived from the history of science. *Research in Science Education, 39*(1), 57–73.

Develaki, M. (2019). Methodology and epistemology of computer simulations and implications for science education. *Journal of Science Education and Technology, 28*(4), 353–370. https://doi.org/10.1007/s10956-019-09772-0

Gresch, H., Hasselhorn, M., & Bögeholz, S. (2015). Enhancing decision-making in STSE education by inducing reflection and self-regulated learning. *Research in Science Education, 47*(1), 95–118. https://doi.org/10.1007/s11165-015-9491-9

Guo, G.P., Xiao, B.Y., & Liu, X.Y. (2021). STSE education: Connotation, type and dimension. *Education in Chemistry*, *11*, 7–12.

Heering, P. (2006). Regular twists: Replicating Coulomb's wire-torsion experiments. *Physics in Perspective, 8*(1), 52–63.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*(7), 551–578.

Kim, M., Yoon, H., Ji, Y. R., & Song, J. (2012). The dynamics of learning science in everyday contexts: a case study of everyday science class in Korea. *International Journal of Science and Mathematics Education, 10*, 71–97. https://doi.org/10.1007/s10763-011-9278-z

Lau, K. C. (2013). Impacts of a STSE high school biology course on the scientific literacy of Hong Kong students. *Hong Kong Institute of Education, 14*(1), 1–25. http://www.ied.edu.hk/apfslt

Lederman, J. S., & Stefanich, G. P. (2006). Addressing disabilities in the context of inquiry and nature of science instruction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science*, 55–74. Springer.

Lederman, N., & Lederman, J. (2014). Research on teaching and learning of nature of science. In N. Lederman & S. Abell (Eds.), *Handbook of Research on Science Education*, 600–620. New York.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education,* 831–879. Mahwah.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521. https://doi.org/10.1002/tea.10034

Lederman, N. G., & Lederman, J. S. (2012). *Nature of scientific knowledge and scientific inquiry: building instructional capacity through professional development*. In Fraser, B. J., Tobin, K. G., & McRobbie, C. J. (Eds.). Second international handbook of science education, (p. 335) Springer International Handbooks of Education.

Li, S. Y., Liu, X. B., & Chen, Y. F. (2020). Teaching design based on the concept of "STSE": Take "free-fall motion" as an example. *Teaching Reference of Middle School Physics, 49*(4), 60–62.

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2008). Preservice teachers' views about nature of scientific knowledge development: An international collaborative study. *International Journal of Science and Mathematics Education, 7*(5), 987–1012. https://doi.org/10.1007/s10763-008-9140-0

MacLeod, K. (2013). Physics education and STSE: Perspectives from the literature. *European Journal of Physics Education, 4*(4), 1–12.

Matthews, M. R. (2012). Changing the focus: From nature of science (NOS) to features of science (FOS). In M. S. Khine (Ed.), *Advances in nature of science research*, 3–26. Dordrecht.

McComas, W. F. (2014). Benchmarks for science literacy. In *The language of science education*, 12. Rotterdam.

McDonald, C. V., & McRobbie, C. J. (2012). Utilising argumentation to teach nature of science. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second international handbook of science education*, 969–986. Springer.

Mesci, G. (2016). *Preservice science teachers' pedagogical content knowledge for nature of science and nature of scientific inquiry: a successful case study*. PhD dissertation, Western Michigan University, USA.

Mesci, G. (2020). The influence of PCK based NOS teaching on preservice science teachers' NOS views. *Science & Education, 29*, 743–769. https://doi.org/10.1007/s11191-020-00117-7

Metz, D., & Stinner, A. (2007). A role for historical experiments: Capturing the spirit of the itinerant lecturers of the 18th century. *Science & Education, 16*(6), 613–624. https://doi.org/10.1007/s11191-006-9016-z

Ministry of Education of the People's Republic of China. (2017). *Notice of the ministry of education on the issuance of the science curriculum standards for compulsory education in primary schools*. http://www.moe.gov.cn/srcsite/A26/s8001/201702/t20170215_296305.html

Murphy, C., Smith, G., & Broderick, N. (2019). A starting point: provide children opportunities to engage with scientific inquiry and nature of science. *Research in Science Education*, 1–35. https://doi.org/10.1007/s11165-019-9825-0

NGSS Lead States. (2013). *Next generation science standards: for states, by states.* Washington.

Olson, J. K. (2018). The inclusion of the nature of science in nine recent international science education standards documents. *Science & Education, 27*, 637. https://doi.org/10.1007/s11191-018-9993-8

Organisation for Economic Co-operation and Development. (2016). PISA 2015 assessment and analytical framework: Science, reading, mathematic, financial literacy and collaborative problem solving (Revised edition). Paris.

Pedretti, E., Bencze, L., Hewitt, J., Romkey, L., & Jivraj, A. (2008). Promoting Issues-based STSE perspectives in science teacher education: problems of identity and ideology. *Science & Education*, *17*(8–9), 941–960. https://doi.org/10.1007/s11191-006-9060-8

Pedretti, E., & Nazir, J. (2011). Currents in STSE education: Mapping a complex field, 40 years on. *Science Education, 95*(4), 601–626. https://doi.org/10.1002/sce.20435

Priyambodo, E., Fitriyana, N., Primastuti, M., & Aquarisco Duo Artistic, F. (2020). The role of collaborative learning based STSE in acid base chemistry: Effects on students' motivation. *Advances in Social Science, Education and Humanities Research, 528*(2), 253–263.

Rudge, D. W., & Howe, E. M. (2009). An explicit and reflective approach to the use of history to promote understanding of the nature of science. *Science & Education, 18*(5), 561–580.

Schellinger, J., Mendenhall, A., Alemanne, N., Southerland, S. A., Sampson, V., & Marty, P. (2019). Using technology-enhanced inquiry-based instruction to foster the development of elementary students' views on the nature of science. *Journal of Science Education and Technology, 28*(4), 341–352. https://doi.org/10.1007/s10956-019-09771-1

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*(4), 610–645.

Silva, F., & Neves, M. (2020). An STSE teaching approach with the theme physics of transportation. *Physical Education Course, 32*, 313–320.

Solbes, J., & Traver, M. (2003). Against a negative image of science: History of science and the teaching of physics and chemistry. *Science & Education, 12*(7), 703–717.

Surpless, B. E., Bushey, M. M., & Halx, M. D. (2014). Developing scientific literacy in introductory laboratory courses: A model for course design and assessment. *Journal of Geoscience Education, 62*, 244–263.

Williams, C. T., & Rudge, D. W. (2019). Effects of historical story telling on student understanding of nature of science. *Science & Education, 28*, 1105–1133.

Yalaki, Y. (2016). Improving university students' science-technology-society-environment competencies. *International Journal of Progressive Education, 12*, 90–98.

Yulianti, D. (2017). Problem-based learning model used to scientific approach based worksheet for physics to develop senior high school students characters. *Journal of Physics: Conference Series, 824*, 012009. https://doi.org/10.1088/1742-6596/824/1/012009