# Difficult topics in the nature of science: An alternative explicit/reflective program for pre-service science teachers

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This study aimed to examine the development of pre-service science teachers' views of the targeted nature of science (NOS) aspects, which are considered more difficult to develop than other aspects. This study was grounded by conceptual change and experiential learning theory. A multiple comparative case study approach was used to explore seventeen pre-service science teachers' views of the targeted NOS aspects through explicit/reflective instruction. This study was carried out within the scope of a science method course allocated three hours per week. Data were collected by using an open-ended questionnaire, follow-up interviews, classroom observations, and reflection essays. Analysis shows the pre-service science teachers had generally naïve and transitional views at the beginning of the study. After intensive NOS instruction focusing specifically on tentativeness, theory/law, and socio-cultural embeddedness of scientific knowledge, the students dramatically developed their views and attained informed understandings in all three NOS aspects. They mostly emphasised the importance of the whole six weeks of NOS instruction including contextualised activities, readings, classroom discussions, lesson plan preparing and presenting, and informal school trips.

## Introduction

One of the most important goals of science education programs across the world is to raise scientifically literate individuals (AAAS, 1993; MoNE, 2018; NGSS Lead States, 2013; NRC, 2000; Lederman, 2007). Science literacy is the ability of all citizens to understand and explain some scientific concepts and phenomena at the most basic level and to use these abilities in their daily lives. Scientifically literate individuals perceive the philosophy of nature of science (NOS) and scientific knowledge, and understand basic science concepts, principles, laws and theories and use them appropriately (NGSS Lead States, 2013). In this sense, learning of NOS and the characteristics of scientific knowledge is crucial for developing scientific literacy. The most important role in achieving this goal falls on science teachers. It is of great importance for achieving this goal for teachers to understand the conceptions of NOS properly and to integrate it effectively in their lessons. Unfortunately, studies have shown that teachers and so students at all levels do not have a proper understanding of NOS (Deng Chen, Tsai & Chai, 2011; Herman, 2018; Lederman, 2007; Lederman & Lederman, 2014).

NOS commonly refers to the nature of the scientific enterprise and the characteristics of the knowledge it produces. Lederman (2007) defined NOS as a way of explaining the natural world, epistemology of science, the role of scientists, and values and beliefs unique to the development of scientific knowledge. There is no consensus among science education researchers regarding the aspects that give shape to NOS (e.g. Erduran & Dagher, 2014; Irzik & Nola, 2014; Lederman, 2007; McComas, Almazroa & Clough, 1998). However, a set of generalisations as convenient for students to learn are widely accepted (Lederman, 2007; Lederman & Lederman, 2014; McComas, 2004; NGSS Lead States, 2013; Schwartz & Lederman, 2008). The common features of scientific knowledge are that: (a) science is based on empirical evidence; (b) Scientific knowledge is tentative, but durable; (c) there is no single scientific method that all scientists must follow; (d) science is based on observations and inferences; (e) creativity/imagination is a vital component of science; (f) subjectivity (both personal and theory-laden) is an inevitable aspect of scientific knowledge as a human endeavour in the production of scientific knowledge; (g) Laws and theories are related but distinct kinds of scientific knowledge, and one can never change into the other; and (h) science affects society and cultures, and it is affected by these factors within which it occurs (Lederman, 2007; McComas, 2004; Mesci & Schwartz, 2017).

How to teach NOS most effectively has been studied for a long period. There are mainly two approaches for teaching NOS, an implicit approach and an explicit/reflective approach. Empirical studies support that an explicit/reflective approach is more effective in developing learners' views of NOS than an implicit approach (e.g. Cofre et al., 2019; Khishfe & Abd-El-Khalick, 2002). Explicit/reflective instruction refers to purposeful teaching of the targeted NOS aspects via having specific learning outcomes that focus students' attention on NOS concepts, enabling them to explore and inquire, reflect on their experiences, and assess their NOS understanding (Abd-El-Khalick & Akerson, 2004; Mesci, 2016; Mesci & Schwartz, 2017; Pavez, Vergara, Santibañez & Cofré, 2016).

Although explicit/reflective NOS instruction is considered a very effective approach for developing individuals' NOS views, it has been found that the desired success has not been achieved for all learners, or there is a limited success in some NOS aspects (Cofre et al., 2019; Lederman & Lederman, 2014; Mesci & Schwartz, 2017). More recently, Cofre et al. (2019) reviewed 52 articles addressing effectiveness of NOS teaching to various groups of people including students and teachers. This review was specifically focused on the changes of participants' NOS understanding after an intervention, which mostly incorporated both contextualised and non-contextualised activities, with major range of methods and designs. According to this literature review, Cofre et al. (2019) revealed that some NOS aspects are more difficult to be altered than others. The difficult aspects to learn were usually tentativeness, socio-cultural embeddedness, and distinguishing between theory and law (Cofre et al., 2019; Mesci & Schwartz, 2017). Besides, it has been shown that these aspects are the least chosen aspects by the pre-service science teachers (PSTs) for teaching NOS (Mesci, 2016). In this regard, it has become necessary to reveal some differences in explicit/reflective NOS teaching, based on some studies which showed the possible factors influencing NOS learning (Clough, 2018; Mesci & Schwartz, 2017), to achieve the desired level of success in the all NOS aspects and to develop the individuals' NOS views successfully. Thus, this study aims to examine the development in the PSTs' views of targeted NOS aspects (tentativeness, theory/law, and socio-cultural embeddedness), which are considered to be much more difficult to alter than other aspects. The research questions leading to this study are:

- How do PSTs change their understandings of the targeted NOS aspects (tentativeness, theory/law, and socio-cultural embeddedness) after a NOS instruction?
- How do PSTs think about the whole process that affects their understanding of targeted NOS aspects?

This study was grounded by conceptual change (Posner, Strike, Hewson & Gertzog, 1982) and experiential learning theory (Kolb, 1984). In conceptual change theory, individuals use their existing knowledge to create new knowledge through determining whether a new concept is understandable, acceptable, and effective (Hewson, 1992). Experiential learning theory involves the teaching of experiencing and learning from this experience. Kolb (1984) defined this theory as the process by which knowledge is created through the transformation of experience. Kolb (1984) proposed four stages in the experiential learning cycle (doing, thinking, conceptualisation, and re-doing). This is a way for people to understand their experience and ultimately change their behaviour. The process of learning in this theory may begin at any stage and is continuous (Kolb, 1984). Conceptual change and experiential learning theory were also used and recommended for further studies into teaching NOS (Abd-El-Khalick & Akerson, 2004; Mesci, 2020; Mesci & Schwartz, 2017).

## Method

A multiple comparative case study approach (Creswell, 2007) was used to examine a group of PSTs developing their views of the targeted NOS aspects through explicit/reflective instruction. Using case studies enables researchers to bring a deep understanding of a case and to provide intrinsic knowledge and details regarding a problem or issue (Stake, 1995). As case studies can be distinguished by the intent of the researchers (Creswell, 2007; Merriam & Grenier, 2019; Yin, 2009), this study is a multiple comparative case study which focuses on a problem, and one limited case (a group of seventeen PSTs over six-weeks) to illustrate the changes of their views about targeted NOS aspects.

### Participants

Seventeen PSTs, who choose the profession of teaching science at middle school (age range: 11-13; grade range: K6- K8), participated in this study voluntarily. They were all seniors in their teacher preparation program (third year of a four-year BEd program) at a state university in the U.S., majoring in science education. They were White American (n=11), African American (n=2); Hispanic (n=2), and Asian (n=2); gender distribution female=10, male=7, and age range 19-24 years. All PSTs had similar educational backgrounds. They all took biology, physics, chemistry, and earth science courses. However, they had never taken any NOS courses before the current study. Pseudonyms are used for the participants.

### Context of the study and data collection

This study was implemented within a science method course conducted with 3 classroom hours per week during the Spring 2019 semester. Only 6 weeks of the course were included in this study (Table 1). At the beginning of the course, each PST who had volunteered to participate in the study completed the *Views of Nature of Science Questionnaire* (VNOS) (Lederman et al., 2002). The VNOS survey is an open-ended instrument that has been validated and widely used to assess NOS conceptions (Abd-El-Khalick, 2014). The VNOS questionnaire consists of 7 open-ended question which allow respondents to use their own words and examples, without being forced into a choice and/or words being chosen for them. Questions based on open ended responses included, for example, "What, in your view, is science? How can you determine when something is science (such as biology or physics) and when something is not science (such as religion or philosophy)?"; and "Scientists try to find answers to their questions by doing investigations. Do you think that scientists use their imagination and creativity in their investigations?"

After completing the questionnaire each pre-service teacher was interviewed individually. During the pre-interviews, the responses of the pre-questionnaire were shown to participants, and they were asked to clarify and elaborate on their answers. By taking into account the recommendations for NOS teaching by Abd-El-Khalick and Akerson (2004); Akerson, Weiland, Ponsgsanon and Nargund (2010); and Mesci & Schwartz (2017), this study was designed based on the following guidelines to teach all the targeted NOS aspects purposefully: (a) goals and objectives specified for NOS were explicitly provided; (b) giving appropriate concepts and vocabulary helped PSTs to understand NOS; (c) reading and discussions from contemporary and history of science were carried out; (d) provocative questions encouraged the establishment of links between critical thinking and NOS aspects; (e) reflection essays aroused PSTs to develop and reinforce their understandings; (f) with the guidance of the instructor, group sharing enabled PSTs to share ideas and experiences; (g) visiting middle schools and universities for increased positive attitudes and motivation towards teaching profession and science; and (h) enabled PSTs to transfer their knowledge into their teaching practice.

*Contextualised NOS activities*

In the first four weeks, explicit/reflective NOS teaching was conducted to develop the targeted NOS aspects (tentativeness, theory/law, socio-cultural embeddedness). Explicit/reflective instruction included classroom activities focused on the targeted NOS aspects, reading assignments, examples from contemporary and history of science, and classroom discussions. In this sense, five contextualised NOS activities were conducted: natural selection/evolution; Boyle's law/kinetic molecular gas theory; global warming/greenhouse effect; atomic models; and relativity/gravity (an example of the contextualised explicit/reflective instruction is provided in the Appendix). Journal articles and chapters (DeBoer, 2000; Gribbin, 2003; Lederman, 2007; Maura & Silva, 2018; McComas, 2004) were read and subsequent class discussions were followed to expand the PSTs' worldview and to reinforce their learning (Table 1).

Table 1: Context of the study and data collection

| Time | | NOS instruction | Data collect. |
|---|---|---|---|
| 4 weeks | Contextualised NOS activities/ targeted NOS aspects | • Natural selection/evolution (Theory/law; socio-cultural embeddedness)<br>• Boyle's law/kinetic molecular gas theory (Theory/law)<br>• Global warming/greenhouse effect (Tentativeness; Socio-cultural embeddedness)<br>• Atomic models (Tentativeness; Theory/law; Socio-cultural embeddedness)<br>• Relativity/gravity (Tentativeness) | VNOS Pre + Interview<br><br>Reflection essays |
| | Reading articles/Book chapters | • DeBoer, 2000<br>• Gribbin, 2003<br>• Lederman, 2007<br>• Maura & Silva, 2018<br>• McComas, 2004 | |
| | Motivational activities (after school hours) | • School trips (meeting with expert teachers, administrators, and students)<br>• Trips to science labs in the university (meeting with scientists) | |
| 2 weeks | Lesson plan preparing and presenting | • Preparing a lesson plan with peers<br>• Presentations<br>• Classroom discussions/feedback<br>• Revising plans and Poster Fair | VNOS Post + Final interview |

*Motivational activities*

In order to increase the pre-service teachers' motivation towards both the teaching profession and science, a series of informal activities were carried out. PSTs went to middle schools to meet students, experienced teachers, and school administrators, to develop positive attitudes towards the teaching profession. Also, PSTs visited the main laboratories at the University and met the scientists to help develop a positive attitude towards science.

PSTs wrote reflection essays in each of the first four weeks (Table 1), comprising three paragraphs based upon three questions (what did you learn today? how does today differ from what you already know? and what more do you want to learn?). These essays formalised and reinforced PSTs' understanding, and also provided instructors with an opportunity to revise NOS teaching for the next lesson.

*Lesson plan preparing and presenting*

As mentioned in the literature, PSTs generally avoid using tentativeness, theory/law, and socio-cultural aspects to include in their teaching. They focused mainly on other NOS aspects (e.g., observation/inferences, creativity, subjectivity, multiple scientific methods) (Mesci, 2016). This might be presumed to make it difficult to meaningfully understand some aspects of NOS, due to their inadequate content knowledge. For this reason, in the last two weeks of the study, PSTs were paired (two people in each group), and asked to prepare a lesson plan for specifically teaching tentativeness, theory/law, and socio-cultural embeddedness to learn from their own experience and their peers, and to increase their motivation through teamwork. In this manner, each group of PSTs prepared a lesson plan and presented it to their peers. Lesson plan presentations were allocated 10 minutes and in-class discussions were followed up. All lesson plan presentations and follow-up discussions were audio-recorded for further analysis. Then, each group revised their lesson plans based on the discussions and feedback and turned them into posters to present at a poster fair at the University.

At the end of the 6 weeks, the VNOS questionnaire was implemented, and the final interviews were followed with each pre-service teacher. In the final interview, in addition to clarifying the responses in the questionnaire, one purpose was to include PSTs in a member checking process by asking questions concerning what they thought about "the whole 6-week process", "which stage they learnt more", and "what was the most important element affecting their learning, or not learning".

All the activities were applied in the same way for all students, both those who participated in this study and those who did not. However, data collected from those who did not participate in this study has not been not included in this analysis.

## Data analysis

VNOS questionnaire and follow-up interviews were analysed by using the NOS views continuum scale for targeted NOS aspects (Schwartz, 2007). PSTs' views were described from naive "-" to mixed "(+)" to increasing levels of understanding "+, ++, +++". Naive "-" range indicates that the PSTs' understanding are not on the same line with views accepted in the current literature regarding the specific aspects of NOS. The Transitional " (+)" range refers to participants' inconsistent or unsettled views. The "+" range indicates that the participants agree with the accepted NOS views; the "++" range demonstrates the ability of participants to express the accepted NOS views; and the range "+++" indicates the participants' successful expressions of the meaning of the particular NOS aspects in their own words by supporting them with appropriate examples (Mesci & Schwartz, 2017).

The scale allows the researchers to analyse the participants' views and changes in these views in a spectrum to see these changes more clearly (Mesci & Schwartz, 2017; Schwartz. 2007). The data concerning reflection essays, final interview transcriptions, and classroom audio-recorded transcriptions were analysed by using content analysis for understanding the effectiveness of NOS instruction on PSTs' NOS views. Three experts analysed about 20% of the data independently. Their analyses were compared and differences were resolved by further discussion of the data until 90% consensus was reached. Then, the author performed all remaining data analyses and interpretations (Miles & Huberman, 1994).

## Results

### Participants' views of targeted NOS aspects

At the beginning of the study, PSTs generally had naïve and transitional views of the targeted NOS aspects. After intensive NOS instruction specifically focusing on the targeted NOS aspects (tentativeness, theory/law, and socio-cultural embeddedness), it was found that the PSTs developed their views and had informed understandings in all these three NOS aspects. Table 2 shows representative illustrations of the targeted NOS aspects by PSTs.

Table 2: Pre-service science teachers' representative views of the targeted NOS aspects

| NOS aspects | Naïve or transitional views | Informed views |
|---|---|---|
| Tentativeness | I don't think that scientific theories and laws we have today will change in the future because they were depending on strong experiments and observations such as observing that an apple falls to the ground when dropped. Scientific theories and laws we have today were proven true and definite. (Pre-VNOS, Nicholas)<br><br>No, I do not believe the theories and laws will change. They have been tested and proven consistently without fail or contradictions. (Pre-interview, Janet) | Theories have the potential to change in the future, since there can be addition to why some things occur with the new data and evidence. Laws also have the potential to change as well, but will not as likely as theories because they are already a combination of the natural phenomena/ occurrences. (Post-VNOS, William)<br><br>Scientific knowledge is always changing with each new research, so it is very possible that the theories that we have today may end up being "upgraded" or possibly even scrapped in the future. Scientific laws may not change as easily as theories. However, it could still be possible to it to change, but it is not as likely. (Post-VNOS, Janet) |
| Theory/ law | Theories are unproven educated guesses. The theory of evolution: This is not something that can be proven definitively. A scientific law something we can test and prove directly, it is indisputable. It will always happen; law of gravity." (Pre-VNOS, Larry)<br><br>Scientific theories are powerful predictions, but not everyone can agree, like big bang theory. If it is accepted and proven by everyone, it becomes a scientific law, like gravity. (Pre-VNOS, Skyler) | A scientific theory is a logical explanation for how and why things happen the way they do based on evidence. The theory of relativity; it's a theory because it is an explanation based on a phenomenon that we encounter. A scientific law is a description of what things happen based on observations and preconceptions of initial conditions. The Pressure gas law; When you have a certain temperature and volume at an initial condition, you can describe the pressure of that system as well. (Post-interview, Eric)<br><br>Germ theory; this theory because it explains how or why diseases are spread by microorganisms, Law of gravity; this is a law |

| | | |
|---|---|---|
| | | because it describes the similar natural phenomena widely observed and comprised of many universally-recognized occurrences. (Post-VNOS, Mai) |
| Socio-cultural embedd-edness | Science is universal. Many of the research that has happened and resulted in significant findings have been performed in different countries. For example, the structure of the DNA double helix was determined by scientists working in England. Every country has their own presentation of science. For example, the metric system is not used in our society, but every country understands the science behind projectile motion. Whether your distance has been measured in feet or meters, you can still calculate and understand physics concepts. Science itself is not affected by cultural or political views. (Pre-interview, Lucy)<br><br>Science is universal, such as the laws of physics. I think that these huge universal concepts are distinct form culture or society. (Pre-VNOS, Eaton) | Science is oftentimes a social and cultural product. Scientific data can oftentimes be taken and manipulated in ways that reflect specific agenda. An example is the 2016 El Nino and La Nina. Breitbart, a right-wing news site, claims that a global temperature drop was due to the weather systems, and the weather systems themselves were random. Other, more moderate or liberal sites, such as the Guardian claim that these weather systems were abnormal because of climate change by human impact. Different societies and cultures can apply the same scientific data differently. Science should not be subjective in this way, but it oftentimes is. (Post-interview, Nancy) |

**Tentativeness**

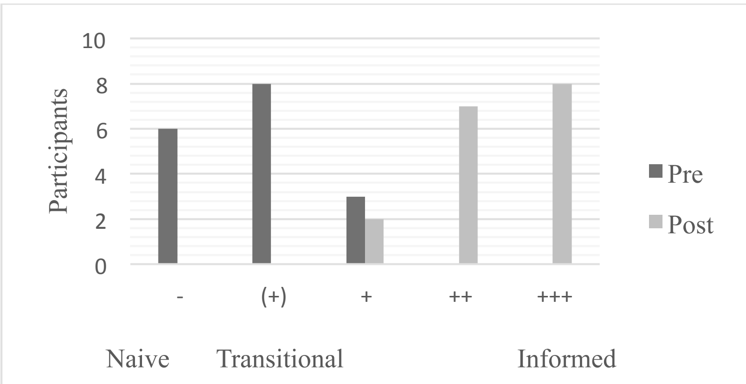



Figure 1: Views in relation to tentative NOS

The PSTs have generally naïve (n=6) and transitional (n=8) views on the tentativeness of scientific knowledge before participating in this study (Figure 1). They stated that scientific knowledge will not change in the future because it was proved to be true and certain. It was seen that some of the PSTs argued that only theories will change in the future because the theories are not definite and scientists do not agree on the theories. Most of them believed that scientific laws will definitely stay the same and not change in the future.

After the six-weeks intensive NOS instruction, all PSTs (n=17) have developed their views about the tentative of scientific knowledge (Figure 1). PSTs stated that scientific knowledge is subject to change in the light of new evidence, developing technology, or alternative ways of thinking. They also recognised that scientific knowledge has strong evidence so it is durable and long lasting. Therefore, they highlighted that even theories and laws that we have today may change in the future.

*Theory / law*

At the beginning of the study, almost all PSTs (n=13) generally had naive views about the meaning of scientific theories and laws. They believed that scientific theories are just temporary guesses, while the scientific laws are scientific explanations accepted by everyone. They stated that if theories are accepted and proven by the all scientists, they become laws. On the other hand, it was seen that some of the PSTs (n=3) could not fully express this aspect of NOS and gave inconsistent answers; they were in transitional range (Figure 2).

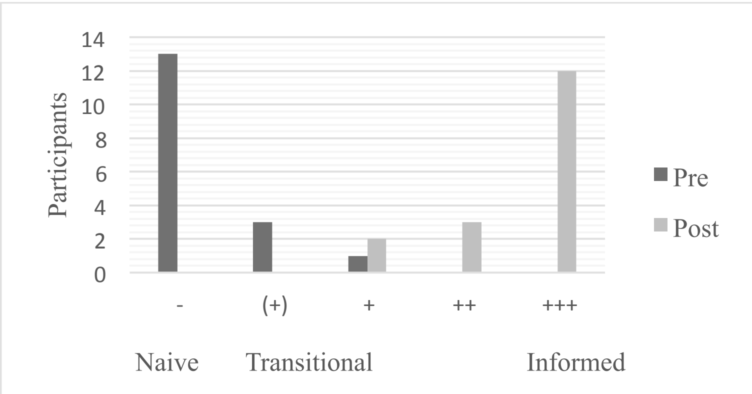



Figure 2: Views in relation to scientific theory and law

After the six-weeks NOS instruction, all PSTs (n=17) have developed their views about the distinction and relationship between scientific theories and laws (Figure 2). PSTs expressed that scientific theories and laws are two distinct types of knowledge and one can never change into the other, but they both have substantial supporting evidence and are widely accepted by scientists.

*Socio-cultural embeddedness*

Before participating this study, PSTs had mostly naïve (n=6) and transitional (n=7) views about the socio-cultural embeddedness of scientific knowledge (Figure 3). They believed that science is universal and not influenced by cultural or political views.

After the six-weeks intensive NOS instruction, all PSTs (n=17) had dramatically developed their views about the socio-cultural embeddedness of NOS. PSTs claimed that science as a human endeavour is practised in a larger culture context, and scientists are the product of this culture. They stated that science is influenced by the various factors and contexts of the culture (social structure, power, politics, socio-economic factors, and religion) in which it is carried out.

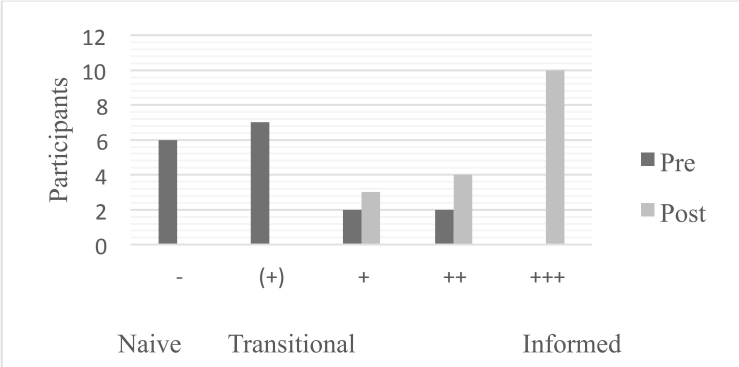



Figure 3: Views in relation to socio-cultural embeddedness of NOS

**Participants' views about the whole 6 weeks period**

The analysis of the final interviews, reflection essays, and classroom discussions shows how important the 6-week NOS teaching is in helping PSTs develop their views on the targeted NOS aspects.

PSTs mostly emphasised the importance of the contextualised activities, readings, and classroom discussions on developing their understandings.

> When scientific laws and the tentativeness of scientific knowledge were mentioned, the law of gravity was always coming to my mind and I was thinking that science is absolute and never change. In our class activities and discussions, we had talked about many examples, like Newton's laws and Einstein's theory, and these examples made me think in a broad perspective. So now, I know that scientific knowledge, even a law or a theory might be tentative, but durable. (Post-Interview_Emerson)

> Today, I have learned about how scientific knowledge is influenced by scientists' socio-cultural life, political and religious views, and their educational background. In the classroom activity (global warming/greenhouse effect), we discussed that global warming is caused by greenhouse gases, but whether it is result of human activity or it is the natural cycle of the earth. Our research in the classroom shows that this debate is still represented by different perspectives in the scientific world. And, I have seen here that the foreign policy of the countries that support scientists and projects in particular is the main causes of this discussion. In another example, in the activity of evolution and natural selection, I have understood the impact of religious views in the evolution research for centuries and the reflections of cultural life in the work of scientists. (Reflection Essay/Day 3_Nicholas).

The quotations below from pre-service teachers about the tentativeness of scientific knowledge indicate the effectiveness of the contextualised activities and journal articles.

> With expanding technology and new evidence, we are able to see the world in macroscopic and microscopic ways that have never before seemed possible. We are piggy backing on theories that have been proposed in the past, such as Copernicus thinking that the sun was the centre of the universe and that the planets orbited around it. Well, he had the correct model about the planets orbiting around the sun, but we now know with increasing technology and the new data that we have that the sun is not the centre of the universe, nor even the milky way galaxy. In this way, we have built on to a theory from the past and constructed a more accurate model of the world. I have read it from an article or a chapter that you recommended, regarding to scientific laws, initially my mind immediately goes to black holes and I want to say well if we could somehow figure out a way to dance on the event horizon…. But isn't time relative regardless? So, shouldn't phenomena behave the same laws there that they would on earth? There would just be a crazy high number in the equation for the pull of gravity. Like a bowling ball and a feather falling down at the same time that we watched and discussed in the class. Scientific laws would change is that if we changed our view to state that time isn't an independent variable, and that it's not always linear. If there was a time "flux" where time was distorted from the pushing and pulling of large quantities of mass over distances that we can't yet calculate or accept for some reason, that would eliminate the idea of restoration of initial conditions, because it would be a completely different time. Even just rolling a ball down a ramp, you couldn't say that it would be the same experiment on take 2 vs. take 1 because the earth has moved to a new location, along with possible fluctuations in the time wave continuum. I want to go down this rabbit hole more and possibly talk about this with you. (Post-Interview_Jessica)

> In fact, I can say that the whole process has been quite beneficial for me to learn. In particular, our class discussions and the process of lesson plan preparing and presenting have led me to reinforced and better understand what I have learned from the activities. (Post-Interview_Janet)

The PSTs also stated that the process of planning lessons and presenting, feedback from instructors and peers, and revising the plans based on the feedback contributed to their understandings of NOS.

> The activities, reading articles, and classroom discussions in the first section were very useful. Then we had the chance to experience what we learned. In particular, your and our friends' feedback after our presentations and the opportunity to revise our plan have enabled us to see and correct our misunderstandings. (Post-Interview_Jesssica)

> While preparing our plan, we thought how to teach the relationship and differences between scientific theory and laws and how to integrate it into genetic subject. We did so much research, also we discussed with you and the professors that we visited, and we got tons of information about the theory and the laws. Now, I feel very comfortable, and when I become a teacher in the future, I think I can use it comfortably in my classes. (Post-Interview_Larry)

In addition, most of the PSTs emphasised the importance of school and laboratory trips, which were intended to increase their motivation towards both teaching proficiency and science teaching.

> Our school trips and conversations with teachers, administrators and students led me to understand how sacred our profession is. When I talked to experienced teachers and

> listened to their great stories, I understood how important a teacher could be in a student's future. When it is considered that nature of science is the basic framework of science teaching, I understood how important it is to teach our students in order to raise a scientifically literate generation. (Post-Interview_Skyler)

> When I visited the labs in the university and met with scientists, I shared with them what I learned and read in our class. and then I was able to better understand the how scientific knowledge is tentative. I also had another discussion with a scientist in the physics lab, she explained why science cannot be considered separate from socio-cultural life of scientists. Through this experience, I have changed the idea of that science is purely universal and should be considered separately from scientists. (Post-Interview_William)

> When I meet the middle school students, I saw their excitement and the happiness that the teacher feels when taught them something, and I really look forward to being a teacher, and I know that learning science is vital. (Post-Interview_Mai)

## Discussion and conclusions

This study aimed to examine the development of pre-service science teachers' views on the targeted NOS aspects (tentativeness, theory/law, and socio-cultural embeddedness), which are considered difficult to be altered (Cofre et al., 2019; Mesci & Schwartz, 2017). The findings of this study indicate that the PSTs in this study developed their naive views markedly in all three targeted NOS aspects throughout explicit/reflective NOS instruction focused specifically on some factors. Although it has been mentioned earlier that explicit/reflective instruction is effective in developing PSTs' NOS understanding (e.g., Akerson, Abd-El-Khalick & Lederman, 2000; Bell, Matkins & Gansneder, 2011; Cofre et al., 2019; Khishfe & Lederman, 2006; Lederman, 2007; Lederman & Lederman, 2014; McDonald, 2010), it is seen that the all individuals may not reach the desired level of success for all aspects of NOS (Cofre et al., 2019; Mesci & Schwartz, 2017). Therefore, explicit/reflective NOS teaching in this study was designed to focus on meta-cognitive and motivational values and resources to conceptually change and improve PSTs' NOS views.

In this regard, NOS teaching, in this study, included resources such as classroom experiences (contextualised activities), examples from contemporary and historical science, discussions, readings, and resources that illustrate the targeted NOS aspects and include links between directions. PSTs should recognise the barriers and flaws in their current ideas to conceptually change their ideas about NOS (Mesci & Schwartz, 2017). They also need to recognise that NOS is important for science teaching, and effectively integrate this value into their science practice (Lederman, 2007). Besides, since it is known that the increasing PSTs' motivation towards both science and the teaching profession contributes positively to their learning (Mesci & Schwartz, 2017), it can be said that informal activities (e.g. school trips; university laboratory visits; meeting with teachers, students, administrators, and scientists) were also effective in learning the targeted NOS aspects in this study. When considering that there was no one left in the naive range and that all participants developed their understandings of the targeted NOS aspects at the end of the study, it is recommended that explicit/reflective NOS teaching should be designed by taking into account conducting contextualised activities, giving more examples from contemporary and history of science, carrying out readings and discussions, increasing pre-service teachers' motivations and worldview, and enabling them to transfer their knowledge into their teaching.

In this study, it should not be concluded that contextualised NOS activities are better than de-contextualised NOS activities. However, it is seen that existing de-contextualised activities are often recommended and applied to teach other NOS aspects (e.g. observation/inference, subjectivity, creativity) (Lederman & Abd-El-Khalick, 1998; Schwartz, Lederman & Smith, 1999). Thus, contextualised activities were specifically used to teach NOS aspects, which are considered more difficult to develop than others, and were found to be effective. In this regard, it is recommended that both contextualised and de-contextualised NOS activities should be designed to teach these difficult NOS aspects, and be examined for effectiveness in future studies. The inclusion of an effective innovation in a course for use by the next and subsequent cohorts can be strong evidence for the utility and efficacy of an innovation. In this regard, the specialised activities conducted for this research (Table 1) could become or be considered a regular component of science methodology courses to integrate NOS into science content, to achieve desired success in aspects of NOS that are considered difficult to teach.

In addition to explicitly integrating contextualised activities into a classroom environment where learners hold naive views, experiences are needed where new ideas or concepts are based on experiential learning. In learning the targeted NOS aspects through their own experiences, especially transferring their knowledge into their teaching, and revising the lesson plans to reinforce their learning, the PSTs emphasised the importance of the process of preparing, presenting, and revising lesson plans, which support the effectiveness of the experiential learning theory as a framework of this study. Concerning both of the theoretical frameworks for this study, it is highly recommended that the goals and objectives specified for NOS should be explicitly provided. Also, journal articles, discussions, and more examples from contemporary and historical science should be carried out with provocative questions to encourage the establishment of links between critical thinking and NOS aspects. Also, PSTs should be forced to integrate all NOS aspects into their teaching explicitly, and be given sufficient time to revise these teachings. PSTs should also be encouraged to write reflection essays for each day to develop and reinforce their understandings. In this regard, as in this study, it is recommended that both experiential learning theory and conceptual learning theory be used for developing PSTs' NOS views.

As suggested in the literature, it is known that intrinsic and extrinsic motivations contribute positively to the PSTs' NOS learning. In this sense, in this study, it was planned to increase the PSTs' motivations towards science and teaching profession throughout the school and laboratory trips to meet with teachers, administrators, students, and scientists. It helped them to learn both science subject matter and the importance and happiness of the teaching profession, and thus helped them to focus on NOS instruction and understand the importance of developing NOS views that are a main component of scientific literacy. In this regard, it is recommended to implement these and similar motivational activities for NOS teaching.

This study is, to some degree, limited to the PSTs who participated and the unique nature of the context. To enable broader generalisations, similar studies in other contexts or with other methods are recommended. Considering that this study represents a different explicit/reflective NOS teaching, it is thought that it will make an important contribution to the existing literature in this field.

## References

Abd-El-Khalick, F. (2014). The evolving landscape related to assessment of nature of science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research in science education*, vol II. New York: Taylor and Francis. https://doi.org/10.4324/9780203097267

Abd-El-Khalick, F. & Akerson, V. (2004). Learning as conceptual change: Factors mediating preservice elementary teachers views of nature of science. *Science Education,* 88(5), 785-810. https://doi.org/10.1002/sce.10143

Abd-El-Khalick, F. & Lederman, N. G. (2000). Improving science teachers' conceptions of the nature of science: A critical review of the literature. *International Journal of Science Education,* 22(7), 665-701. https://doi.org/10.1080/095006900050044044

Akerson, V., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching*, 37(4), 295-317. https://doi.org/10.1002/(SICI)1098-2736(200004)37:4<295::AID-TEA2>3.0.CO;2-2

Akerson, V. L., Weiland, I. S., Pongsanon, K. & Nargund, V. (2010). Evidence-based strategies for teaching nature of science to young children. *Journal of Kırsehir Education,* 11(4), 61-78. http://www.acarindex.com/dosyalar/makale/acarindex-1423907669.pdf

AAAS (American Association for the Advancement of Science) (1993). *Benchmarks for science literacy: A Project 2061 report.* New York: Oxford University Press.

BBC (2014). *Brian Cox visits the world's biggest vacuum* | Human Universe – BBC (video). https://www.youtube.com/watch?v=E43-CfukEgs

Bell, R. L., Matkins, J. J. & Gansneder, B. M. (2011). Impacts of contextual and explicit instruction on preservice elementary teachers' understandings of the nature of science. *Journal of Research in Science Teaching,* 48(4), 414-436. https://doi.org/10.1002/tea.20402

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

Clough, M. P. (2018). Teaching and learning about the nature of science. *Science & Education,* 27, 1-5. https://doi.org/10.1007/s11191-018-9964-0

Cofre, H., Nunez, P., Santibanez, D., Pavez, J. M., Valencia, M. & Vergara, C. (2019). A critical review of students' and teachers' understandings of nature of science. *Science & Education*, https://doi.org/10.1007/s11191-019-00051-3

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches.* Thousand Oaks, CA: SAGE.

DeBoer, G. E., (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science*

*Teaching,* 37(6), 582-601. https://doi.org/10.1002/1098-2736(200008)37:6<582::AID-TEA5>3.0.CO;2-L

Deng, F., Chen, D., Tsai, C. & Chai, C. (2011). Students' views of the nature of science: A critical review of research. *Science Education,* 95(6), 961-999. https://doi.org/10.1002/sce.20460

Erduran, S. & Dagher, Z. R. (2014). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories.* Netherlands: Springer. https://www.springer.com/gp/book/9789401790567

Gribbin, J. (2003). *The scientists: A history of science told through the lives of its greatest inventors.* Random House, New York.

Herman, B. C. (2018). Students' environmental NOS views, compassion, intent, and action: Impact of place-based socioscientific issues instruction. *Journal of Research in Science Education*, 55(4), 600-638. https://doi.org/10.1002/tea.21433

Hewson, P. W. (1992). Conceptual change in science teaching and teacher education. Presented at *Research and Curriculum Development in Science Teachin*g under the auspices of the National Center for Educational Research, Documentation, and Assessment, Ministry for Education and Science, Madrid, Spain, June 1992. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.459.7855&rep=rep1&type=pdf

Irzik, G. & Nola, R. (2014). New directions for nature of science research. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 999-1021). Dordrecht: Springer. https://www.springer.com/gp/book/9789400776531

Khishfe, R. & Abd-El-Khalick, F. (2002). Influence of explicit reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching,* 39(7), 551-578. https://doi.org/10.1002/tea.10036

Khishfe, R. & Lederman, N. G. (2006). Teaching NOS within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching,* 43(4), 395-418. https://onlinelibrary.wiley.com/doi/10.1002/tea.20137

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development.* New Jersey: Prentice-Hall. https://www.pearson.com/us/higher-education/product/Kolb-Experiential-Learning-Experience-as-the-Source-of-Learning-and-Development/9780132952613.html

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* (pp. 831-880). Routledge. https://www.routledge.com/Handbook-of-Research-on-Science-Education/Abell-Lederman/p/book/9780805847147

Lederman, N. G. & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understandings of the nature of science. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 83-126). Dordrecht, The Netherlands: Kluwer Academic Publishers. https://www.springer.com/gp/book/9780792350804

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. (2014). Research on teaching and learning of nature of science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science*

*education volume II* (pp. 600-620). New York: Taylor & Francis. https://doi.org/10.4324/9780203097267
McComas, W. F. (2004). Keys to teaching the nature of science: Focusing on the nature of science in the science classroom. *The Science Teacher,* 71(9), 24-27. https://www.jstor.org/stable/24155554
McComas, W. F., Almazroa, H. & Clough, M. P. (1998). The nature of science in science education: An introduction. *Science & Education,* 7, 511-532. https://doi.org/10.1023/A:1008642510402
McDonald, C. V. (2010). The influence of explicit nature of science and argumentation instruction on preservice primary teachers' views of nature of science. *Journal of Research in Science Teaching,* 47(9), 1137-1164. https://doi.org/10.1002/tea.20377
Merriam, S. B. & Grenier, R. S. (Eds.) (2019). *Qualitative research in practice: Examples for discussion and analysis*. Wiley. https://www.wiley.com/en-au/Qualitative+Research+in+Practice:+Examples+for+Discussion+and+Analysis,+2nd+Edition-p-9781119452027
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. http://scholarworks.wmich.edu/dissertations/1606
Mesci, G. & Schwartz, R. S. (2017). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education,* 47(2), 329-351. https://doi.org/10.1007/s11165-015-9503-9
Mesci, G. (2020). The influence of PCK-based NOS teaching on pre-service science teachers' NOS views. *Science & Education.* 29, 743-769. https://doi.org/10.1007/s11191-020-00117-7
Miles, M. B. & Huberman, A. M. (1994). *Qualitative data analysis* (2nd ed.). Thousand Oaks, CA: SAGE. [4th ed.] https://au.sagepub.com/en-gb/oce/qualitative-data-analysis/book246128
MoNE (Ministry of National Education, Turkey) (2018). *İlköğretim kurumları fen bilimleri dersi öğretim programı [Primary education institutions' science instruction program]*. Ankara, Turkey: Talim Terbiye Kurulu Başkanlığı. http://mufredat.meb.gov.tr/Dosyalar/201812312311937-FEN%20BİLİMLERİ%20ÖĞRETİM%20PROGRAMI2018.pdf
Moura, B. A. & Silva, C. C. (2018). Critical and transformative teachers: A rationale for history and philosophy of science in teacher education. In M. E. de B. Prestes & C. Celestino Silva (Eds.), *Teaching science with context: Historical, philosophical, and sociological approaches* (pp. 3-13). Springer International Publishing. https://www.springer.com/gp/book/9783319740355
National Research Council (2000). *Inquiry and the national science education standards.* Washington, DC: National Academic Press. https://www.nap.edu/catalog/9596/inquiry-and-the-national-science-education-standards-a-guide-for
NGSS Lead States (2013). *Next generation science standards: For states, by states. Washington, DC: National Academies.* [viewed 21 October 2013] http://www.nextgenscience.org/next-generation-science-standards
Pavez, J. M, Vergara, C. A., Santibañez, D. & Cofré, H. L. (2016). Using a professional development program for enhancing Chilean biology teachers' understanding of nature

of science (NOS) and their perceptions about using history of science to teach NOS. *Science & Education*, 25, 383-405. https://doi.org/10.1007/s11191-016-9817-7

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education,* 66(2), 211-227. https://onlinelibrary.wiley.com/doi/abs/10.1002/sce.3730660207

Schwartz, R. S. (2007). Beyond evolution: A thematic approach to teaching NOS in an undergraduate biology course. In *Proceedings of the International Conference of the National Association for Research in Science Teaching*, New Orleans, LA, USA. 15-18 April.

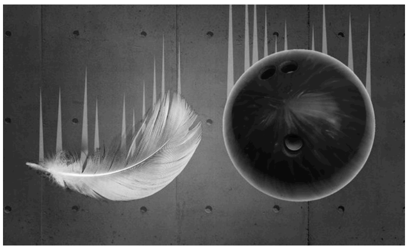
Schwartz, R. S. & Lederman, N. (2008). What scientists say: Scientists' views of nature of science and relation to science context. *International Journal of Science Education,* 30(6), 727-771. https://doi.org/10.1080/09500690701225801

Schwartz, R. S., Lederman, N. G. & Smith, M. J. (1999). Modeling success during Earth science week. *Science Scope,* 23(1), 36-37. https://www.jstor.org/stable/43178481

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: SAGE. https://au.sagepub.com/en-gb/oce/the-art-of-case-study-research/book4954

Yin, R. K. (1994). *Case study research: Design and methods. (2nd ed.)* Newbury Park, CA: SAGE.

## Appendix: Example of explicit/reflective contextualised NOS activity

| NOS activity | Targeted aspects | Instruction<br>(I: Instructor; S: Student) |
|---|---|---|
| Gravity/ relativity | Theory/ law<br><br>Tentati-veness | The lesson was started with a question that will be of interest to the students! "If a bowling ball and a feather are released in at the same time from the same height, which one falls first?"<br><br><br>"This was a question that had intrigued Galileo Galilei. Of course, he didn't think of it as a bowling ball; but the logic was the same: does the larger mass fall faster than different mass objects?"<br>The students generally thought the bowling ball would fall faster.<br><br>Then, the students were divided into groups and asked to design their own experiments. They tested the rate at which various objects fall, noted both the mass of each object, and how long it takes for it to fall. The students were reminded to be sure to drop all objects from the same height. They recorded all their information in a journal, and chart their results. They conducted three trials for each object so that they could calculate an average time. The students were then asked why the objects fall when they were released?<br><br>All students responded: "Gravity".<br>I: What is gravity?<br>S: The force which causes objects to fall.<br>I: So, is gravity a theory? Or is it a law?<br>S: A law… Law of Gravity! |

I: Why is it a law?
S: Because everyone agrees on!
S: Also, there's something called gravitational theory.
I: What is that?
S: I don't really know?
I: What is difference between "Law of Gravity" and "Gravitational Theory"?
……No answer….

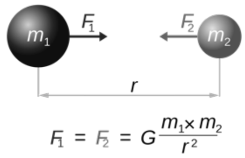
Then, the students were asked to write down all the theories and laws they already knew. All the students took out a piece of paper, and wrote down the theories and laws they knew, then discussed them in the group and listed what they knew about why they could be theory and law. Later, each group made research about the theories and laws, and shared their results with their friends.

After the all groups presentations, the students stated that the theories and laws are different concepts and that they will not turn into each other. They understood that a law defines observable phenomena and that a scientific theory is a well-supported explanation of natural phenomena.

The instructor added the following explanation in relation to the activity;
In the presence of air, 3 forces act on the objects released:

1. Air Resistance: This force is the force experienced by the objects moving in the air due to air friction. This force acts on objects moving towards the ground in the opposite direction to the ground.
2. Lifting Force: Just like swimming in water, the air has a lifting force. But this force is so small that in most cases it can be ignored.
3. Gravity: The force that causes the objects to tend to move towards each other.

Every point mass attracts every single other point mass by a force acting along the line intersecting both points. The force is proportional to the product of the two masses and inversely proportional to the square of the distance between them.




Then, the same question was repeated to the students;
I: What is difference between "Law of Gravity" and "Gravitational Theory"?
S: Law of gravity states that any two masses attract each other with a force equal to a constant multiplied by the product of the two masses and divided by the square of the distance between them.
S: Gravitational theory, actually more than one theory exist, explains why and how an object falls when released.
I: What do you mean by saying "more than one theory"?

S: Newton developed a theory of why and how these movements performed in this way by focusing on the movements of the objects around him. By incorporating the findings discovered from Newton's time to his time, Albert Einstein was able to develop a far more comprehensive explanation (theory) of the nature of gravity.
I: Yes, that's right! Newton's theory is indeed quite functional and is still widely used today. For example, planes, cars, telephones and other electronic devices, buildings, bridges and many other objects that you can think of can be built using Newton's theory. But like every theory, Newton's Gravitational Theory has certain limits.
I: However, if the objects we study are huge mass objects such as stars or galaxies, or if you want to study the behavior of objects moving at speeds close to the speed of light, the error margin of Newton's Gravitational Theory is unacceptable. In the case of such movements, we need to use Einstein's Theory of Relativity.

As students think about different theories and laws, they also started to think about that scientific knowledge is tentative. Then, the instructor asked an additional question related to original question.

I: Normally, if we think in a commonsensical way, we feel that the bowling ball must fall before the feather. i.e. if you release these two objects from the top of a building at the same time, the bowling ball will drop down before the feather. But if there is no air! what do you think? what happens?
S: It would be the same! I mean, bowling ball touched the ground first.
S: I think they both touched the ground at the same time!
I: Why do you think that?
S: I don’t know
I: Well, let's watch Brian Cox's video (BBC, 2014) …. https://www.youtube.com/watch?v=E43-CfukEgs
After all students saw that both objects touched the ground at the same time in an airless environment, they began to realize that the everything is relative.
S: Everything here is a refutation of Newton's laws.
S: So what we know as true today may change in the future with different explanations, new data, and evolving technology.
S: Yes, as Einstein tried to explain in his theory of relativity.
I: Exactly, this theory falsifies two fundamental "truths" that Newton's common sense says:
1. The speed of light is not constant and is variable.
2. Space and time are separate phenomena.
In Einstein's theory, the speed of light is absolutely constant and never changes. Space and time are not independent; they consist of different parts of the same tissue and are inseparably connected.
This situation alters our perceptions about the nature of the Universe. For example, the force called "gravitational" in Newton's Gravitational Theory creates the perception that there is a rope between the objects and that the objects pull each other in a linear way along this rope line. Accordingly, we interpret the Universe in this way.

| | |
|---|---|
| | This makes sense; because Newton's common sense assumes that force must also act linearly because motion is linear. Even the narratives that he developed this theory by looking at a falling apple are an extension of this perception. But this thought is wrong. That is to say, our common sense in the bowling and feather case misleads us; Although Newton had a perception of physics that went far beyond us, he was mistaken for what his common sense said about this very fundamental subject.<br>If we were to explain the Universe as Newton understood, it would be impossible to explain a significant part of our observations of stars that are far, far away from us. For example, we could not explain how the light from more distant stars, such as the Sun, with us, reached the telescopes on Earth. But with the Einstein's theory, we know that gravity is not a linear force; It is a route change experienced by other objects as a result of the bending of space-time plane by large mass objects. This is the first important point Brian Cox mentioned in the video: Gravity is not a force acting along a line; is a result of the bending of the space-time plane. Since there was no direct force, Einstein called it "imaginary" force |
| S: | Honestly, I've never thought about science in this way. I understood that science could change in the light of new data and different theories, and I'm having an enlightenment. |
| I: | However, we should not forget that all the known theories and laws are quite powerful and durable scientific knowledge and have strong scientific evidence. |

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