

A Virtual, Synchronous Nature of Science Activity Sequence Within a Professional Development Workshop

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Abstract

Understanding the nature of science (NOS) has been an important goal of reform efforts in science education around the world to improve the scientific literacy of students. Toward this goal, several NOS intervention studies have focused on improving NOS understanding of teachers and students. Typically, NOS interventions are implemented within science methods courses for preservice teachers or professional development (PD) workshops for inservice teachers. Our PD was designed as a virtual synchronous series of NOS activities to improve NOS understanding among international science educators. The results provide positive impacts of the series on the participants' understanding of NOS. This work also revealed additional insights for the implementation of online NOS PD, taking into account constraints of online implementation.

Future exploration of how to design NOS PD is crucial, especially in countries that have limited resources and research on NOS. Thus, we continue to design ways to bridge this gap and make science accessible to all.

Introduction

Understanding the nature of science (NOS) has been an important goal of reform efforts in science worldwide, aimed at enhancing students' scientific literacy (Kampourakis, 2016; McDonald & Abd-El-Khalick, 2017). Research indicates a growing number of studies focused on the NOS of preservice and inservice teachers in various international contexts (Kartal et al., 2018; Ma, 2015). However, despite emerging reforms in the Middle East and North Africa (MENA), NOS research in these regions remains limited (Alhamlan et al., 2018). For example, the Ministry of Education in Morocco aims to provide elementary students with experiences that mimic working as scientists as part of their science curricular reforms (Moufti et al., 2020). Nonetheless, Morocco's science curriculum continues to emphasize acquiring science content (Dagher & BouJaoude, 2011) and a traditional, step-by-step approach to the scientific method (Lahlou, 2019). This strict adherence to procedural formulas in scientific investigation potentially hinders the goal of accurately conveying how scientists work, thereby limiting students' ability to think and work like scientists.

Recognizing this issue, we implemented an online synchronous NOS teacher professional development (oTPD) workshop for Morocco science and science education professors. This workshop was part of a broader program aimed at improving preservice education in Morocco. The NOS oTPD was designed to engage participants in NOS activities traditionally conducted in person. Scholars have utilized these NOS activities to enhance teachers' understanding of NOS and improve their instructional practices (Akerson et al., 2009; Lederman & Lederman, 2019; Mulvey & Bell, 2017). However, there has been limited implementation of online NOS oTPD to date.

Online Teacher Professional Development (oTPD)

The COVID-19 epidemic has expedited the development, participation, and demand for online courses and activities (Bragg et al., 2021; Hartshorne et al., 2020). Consequently, this enhanced focus on oTPD has also increased distance collaboration, offering convenience for teachers and customized learning opportunities (Amador et al., 2019) and flexibility to access materials (Fenton & Watkins, 2007). In fact, a recent literature review of 73 oTPD studies published in the past ten years revealed a growing inclination toward teacher innovation in teacher collaboration and communities of practice within educational settings (Lay et al., 2020). The authors identified a recurring theme emphasizing the significance of and advancements in teacher cooperation and communities of practice in online environments. For example, a reviewed study (Frumin et al., 2018) examined the involvement of AP science teachers in an online forum that provided many avenues for accessing information while fostering collaboration through the creation of digital platforms. Findings indicated that AP science professors who participated in the online forum, even passively, had improved student performance on AP exams. This suggests that high-quality TPD practices with rich and varied resources, peers, and facilitators are effective and encourage community-based approaches in oTPD. Similarly, Li et al. (2023) conducted a systematic review of 12 peer-reviewed articles and conference papers focused on the efficacy of face-to-face vs online continuous professional development (CPD) for science educators. This study found that online CPD offers geographical flexibility, cost savings, and communities of interest. However, the authors also emphasized that although there is empirical evidence of oTPD benefits, research also reports its limitations. One significant hindrance to oTPD effectiveness is the lack of computers with stable internet access. Additionally, the challenge of establishing a community that facilitates real-time interaction between facilitators and participants obstructs opportunities for idea sharing and knowledge acquisition, potentially negatively impacting learning outcomes. Overall, Lay and colleagues (2020) reported that high-quality oTPD focuses on enhancing the physical components of design, such as improving technology features like “navigability, availability of technical support,” and other forms of assistance (p. 7). For instance, Bragg et al. (2021) found that computer support, including interactive videos, fostered effective oTPD in four of 11 reviewed studies. Taking

into account these benefits and limitations of oTPD, we describe and provide all the resources used during our implementation of a virtual and synchronous instructional sequence of NOS.

Nature of Science

Although there is no single definition of NOS, there are general statements that constitute NOS and are included in science standard documents. The following NOS statements are found in Appendix H of NGSS (NGSS Lead States, 2013, p. 4):

1. “*Scientific Knowledge is Open to Revision in Light of New Evidence.*” Scientific laws, although widely and generally accepted, can change based on new evidence. This process involves repeated studies, numerous observations, and substantial evidence. The revision of theories and laws requires careful and rigorous observation of phenomena.
2. “*Scientific Investigations Use a Variety of Methods.*” Scientific investigations employ various methods, including but not limited to experimentation. While experiments are crucial for some scientists, others, such as astronomers, rely solely on observations due to the inability to control experimental variables. Contrary to the common view of equating science with experimentation, the step-by-step procedure known as “the scientific method” is not the only method used to answer scientific questions (Abd-El-Khalick et al., 2017; McComas, 1998).
3. “*Science is a Human Endeavor.*” Science involves the work of individuals whose diverse backgrounds, including their education, cultural beliefs, and imagination, may influence the creation of scientific knowledge. Consequently, science may be influenced by scientists’ personal biases and perceptual frameworks. Additionally, it is a social activity that allows for collaboration, drawing conclusions, and diverse interpretations from individuals of different cultural and social backgrounds. Thus, science impacts and is impacted by society (*sociocultural*).
4. As a human endeavor, science is *creative*. Scientists use imagination throughout their investigations, including collecting and analyzing data. It is also important to emphasize that creative NOS is a cognitive activity (Brunner et al., 2022); it “involves the invention of explanations” (Lederman, 2007, p. 833).

In our oTPD, we focused on the aforementioned aspects of NOS. Although these aspects are presented as distinct points, we emphasized their interrelated nature to our participants. For instance, we highlighted that scientists employ various methods because their educational and cultural backgrounds influence their investigation processes (sociocultural and subjectivity). These diverse methods can foster creativity in science, leading to the development of new investigative techniques (e.g., Brunner et al., 2022).

The Virtual Synchronous NOS Instructional Sequence

We used *noncontextualized activities* (see Table 1) to teach NOS. Studies (e.g., Abd-El-Khalick & Akerson, 2004; Kruse et al., 2021) have shown that noncontextualized activities—defined as “NOS instruction without an explicit science content” (Mulvey & Bell, 2017, p. 65)—have the potential to improve both teachers’ and students’ understanding of NOS.

Although there are contentions about the contextualization of the NOS intervention, Clough (2006) notes that explicit and reflective *non-contextualized* NOS implementation “directly illustrate important ideas about the NOS” (p. 472). Therefore, we purposely implemented such activities to achieve our primary goal of introducing NOS to our participants and helping them clarify their misconceptions about NOS, as indicated in their pre-NOS survey assessment. Throughout the sessions, we engaged participants in NOS activities that *explicitly* included reflection prompts to encourage consideration of NOS concepts, which are described in each activity below.

The first activity was the “Myth or Truth” Zoom Poll, which explored the participants’ understanding of NOS and introduced NOS ideas. The second set of NOS activities was the “Inquiry Cube” and the “Jamboard Card Exchange,” which focused on helping participants understand that science can be done in multiple ways, can be influenced by personal experiences and backgrounds; and can be impacted by and impacts society and culture. The last activity used an ambiguous image that reinforced the role of multiple perspectives that could influence interpretations of the same phenomenon or data. All these activities are *noncontextualized* because they do not describe the scientific content but emphasize NOS that have been found to be resistant to change, such as the sociocultural aspect of NOS aspect (e.g., Mesci & Schwartz, 2017; Mulvey et al., 2016).

Participants and PD Schedule

A large group of Moroccan preservice elementary science education and science content professors (14 males and 5 females) participated in our PD. These participants self-reported their content specializations, which included biology, chemistry, physics, Earth and Life Sciences, and science education. Participants completed three online PD sessions via Zoom, each lasting approximately 120 minutes. Table 1 shows the NOS activities implemented in each PD session.

Table 1*PD Sessions and Implemented NOS Activities' Purpose and Target Learning Outcomes*

PD Session	NOS Activity	Purpose of the Activity	Learning Outcomes
PD 1 Introduction and Orientation	Poll survey on Myth and Truth about NOS NOS Views Pre- survey	To assess participants' NOS understanding prior to PD	To design purposeful NOS activities targeting less informed NOS conceptions
PD 2 NOS Session Part 1	Virtual Inquiry Cube	To emphasize multiple methods in scientific investigation, role of both observations and inferences in constructing scientific knowledge, influence of scientists' different perception when interpreting data	To identify varied methods of science and reflect on scientists' works
	Card Exchange using Jamboard	To emphasize sociocultural aspect of science and multiple methods in scientific investigation	To create and explain set of NOS related scientific ideas
PD 3 NOS Session Part 2	Ambiguous Images	To emphasize sociocultural aspect of science and influence of scientists' different perception when interpreting data	To reflect on scientists' diverse perceptual frameworks influencing constructing scientific ideas

NOS oTPD Design

In this section, we describe the NOS activities and the implementation procedure. Each NOS activity was implemented to address specific learning outcomes outlined in Table 1. Across all PD sessions, participants were given the option to turn on or turn off their cameras and use the Zoom chat raise hand button features for communication. The participants spoke fluent French and Arabic but spoke English at different proficiency levels. Therefore, one of the authors, who is fluent in French (speaking and writing), served as a translator of the English language into French during the PD sessions. Therefore, we encouraged them to share their ideas using the language they are most comfortable to speak. The participants used either French or English language throughout the session. This sharing of ideas occurred throughout the sessions but primarily during the debriefing sessions (i.e., after implementation of NOS activities). Most of them turned on their cameras. Those whose cameras were turned off during the session would turn it on when sharing ideas. All our other data sources, including survey and activity materials, were translated into French or Arabic. The following are details of the implementation of NOS activities.

PD Session 1

The first PD served as an introductory session that included sharing the importance of teaching and learning NOS. We also informally surveyed participants' NOS views through a survey poll in Zoom (see details about the poll below). At the end of the PD, we asked the participants to respond to exit ticket questions: "What did you learn from the PD?" and "What else do you want to learn (in the next PD)?" The responses were addressed during the second session.

Myth or Truth Zoom Poll

We used an online poll feature in Zoom to survey the initial NOS understanding of participants on the first day of the oTPD. This online poll provided us with informal and immediate results of their NOS understanding. We provided the instructions to create a Zoom Poll survey before the meeting, which are attached in the Supplemental Materials at the end of this manuscript. During the poll, participants determined a “myth” or a “truth” statement about NOS. First, we showed them a slide containing a NOS-related statement (See Figure 1A). Please note that the information on the slides includes translations to accommodate the preferred language of the participants during PD. Then, we asked them to use the Zoom Voting Poll with the choices “Myth” or “Truth” (Figure 1B). After everyone voted, we explained that although science aims for objectivity, it is influenced by personal biases, beliefs, prior knowledge, and experiences (Lederman, 2007; McComas, 1998). Thus, these can influence the choice of problems and the interpretation of results. To reduce subjectivity, scientists share and critique scientific works and seek patterns to establish accurate evidence. We also described that society and culture can impact the work of scientists and vice versa. Thus, science is also sociocultural. This poll activity informally assessed participants’ initial understanding of the NOS understanding and informed the NOS instructions for the subsequent activities. Per the poll and formal NOS survey results (see assessment section below), participants have alternative views on using scientific methods and creativity and subjectivity in scientific investigations. Thus, the succeeding activities focused on these NOS aspects.

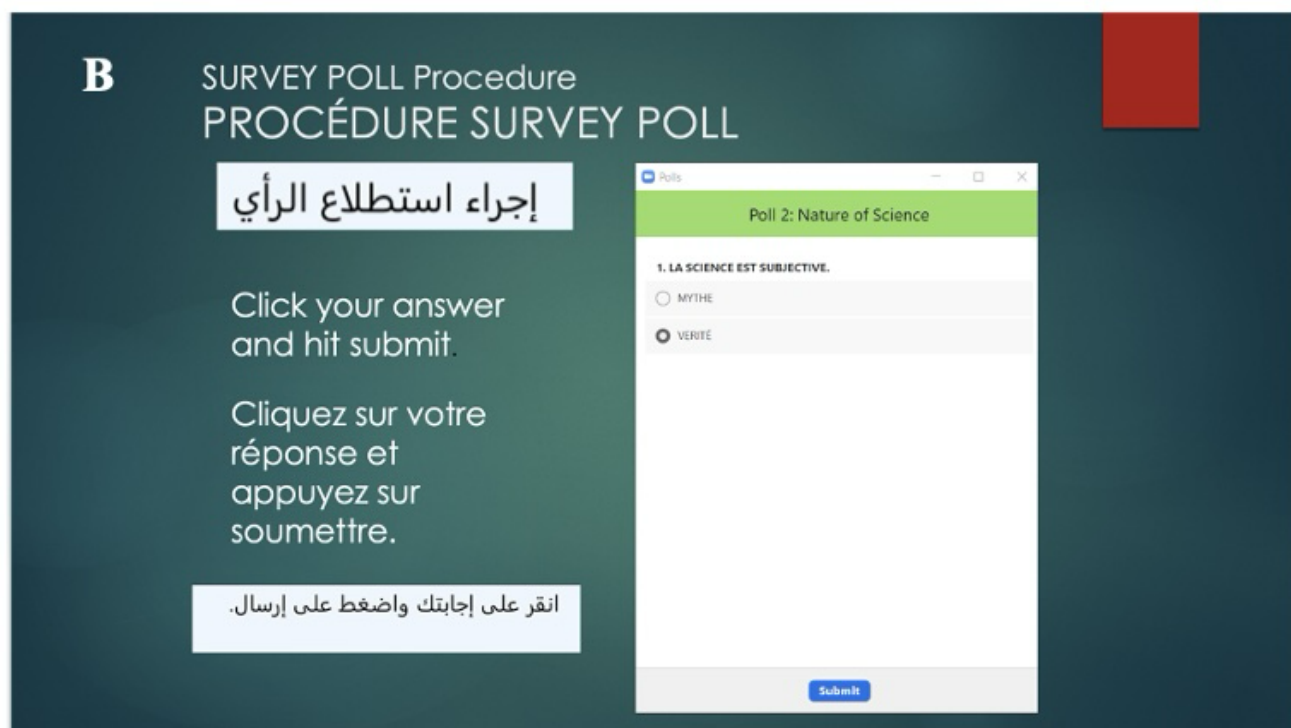
Figure 1

The Use of Different Languages

NOS Statement in Different Languages (A): French Translation (Top); Arabic Translation (Center); English (Bottom)



Instruction to Vote Using the Zoom Survey Poll Translated in Different Languages (B)



PD Session 2

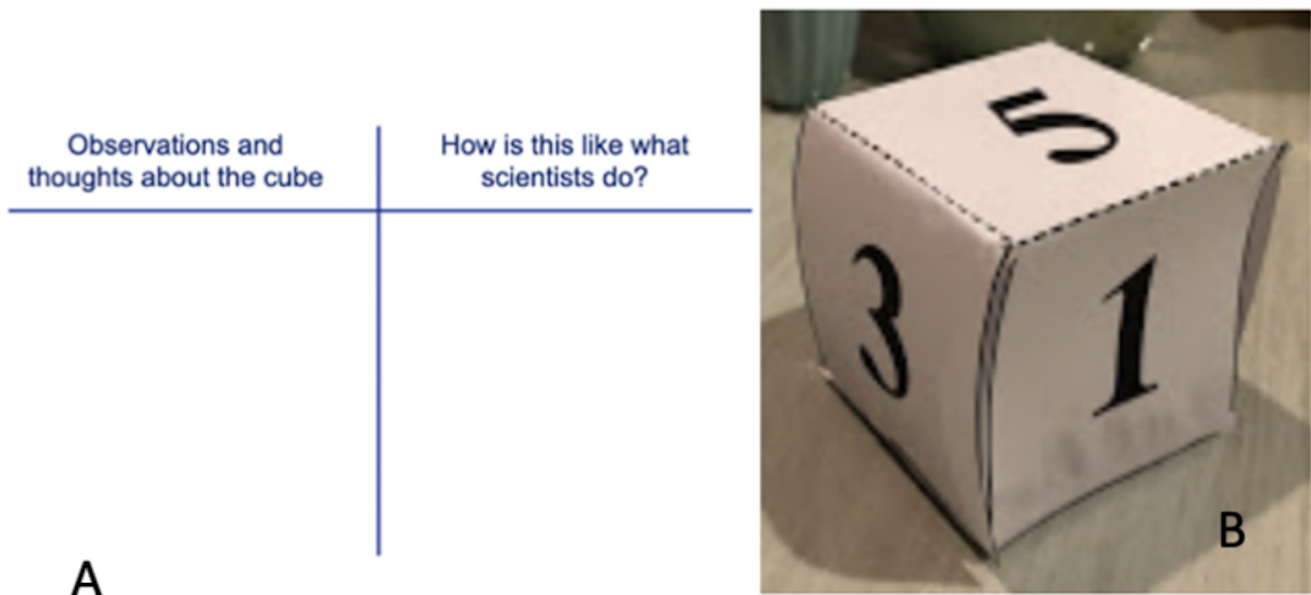
The second PD aimed to address the participants' responses to exit tickets and NOS views survey from session one. The majority of participants possess an alternative view on the use of scientific methods and creativity and subjectivity in scientific investigations. Interestingly, they also expressed the desire to learn how to teach NOS. Therefore, this session provided tested explicit-reflective non-contextualized NOS activities [i.e., modified “inquiry cube” and Jamboard Card Exchange activities] that target understanding of the identified NOS aspects. See details of implementation below.

Inquiry Cube Activity: What is at the Bottom of the Cube?

The “inquiry cube” activity has been traditionally used face-to-face with participants to introduce NOS (Bell, 2008; National Academy of Sciences, 1998), where participants create their own inquiry cubes. We used this activity to help participants identify and engage in varied methods of science [in addition to experimentation] and reflect on scientists' works. For this virtual activity, we used a [video clip](#) (see supplementary materials) showing the cube being turned around without showing the bottom of the cube and asked participants to reflect on how the experience may be similar to the work of scientists. First, we asked the participants to create a *T-table* in their notebooks, as shown in Figure 2A. Next, 3-4 participants went to Zoom breakout rooms to watch the cube video clip. Figure 2B is the cube image in the video clip. We instructed them to use the *T-Table* to record their observations (first column) and to reflect on “How is this like to what scientists do?” (second column) during and after viewing the video. The second column is important to draw participants' attention to NOS. We used the images to show the sides of each cube in figure 3 A-D during the whole group presentation before they moved to their specific breakout rooms.

Figure 2

From Left to Right. (a) A T-table to Record Thoughts. (b) Observations and an Image of the Cube



After their breakout sessions, we asked participants to share their observations and conclusions about the cube. We also asked them to critique each other's arguments. During the debriefing, we explained how their experience with inquiry cube activity may be similar to how scientists work. For example, their differing observations of the same cube can be likened to scientists having different observations of the same phenomenon, influenced by their individual perceptions and backgrounds to draw conclusions. We emphasized that scientists' individual differences influence their interpretation, but they still rely heavily on empirical evidence. Finally, participants responded to the same exit ticket questions as in the first PD at the end of the session.

Figure 3

Different Sides of the Cubes Shown to the Participants



NOS Jamboard Card Exchange

The NOS Jamboard (see supplementary materials), adopted and modified from “Card Exchange” (Cobern & Loving, 2020), is a three-phase group activity to help participants discuss and reflect on selected NOS-related statements. This activity aimed to create and explain a set of NOS-related scientific ideas to emphasize sociocultural and subjective NOS. Given the virtual context, we used the Jamboard [instead of traditional physical cards] and the embedded sticky note to represent each NOS-related statement. First, the participants were divided into groups of four and worked in Zoom breakout rooms. Each group was given a link to the Jamboard with four sets of eight statements grouped into specific colors of sticky notes (Figure 4). During this activity, participants worked in groups to examine NOS statements [including misconceptions about science]. The following are the instructions for each phase:

Phase 1. Selection and evaluation of statements. In your breakout rooms, each participant will choose a set of statements and substitute “participant” with your name (Figure 4). Then, evaluate each statement as to which you most and least agree. Evaluate

statements that are only under your name. When you are done evaluating, give one statement that you least agree with to one of your group members by moving one of your sticky notes to the other set of statements. *Note: You do not discard sticky notes but exchange them with anyone in the group. Also, it does not matter who you want to give your sticky note to if you move it to another set.*

Figure 4

Statements Assigned to Each Participant

Substitute “Participant” with your name			
Participant 1	Participant 2	Participant 3	Participant 4
Science is open-ended, but scientists operate with expectations based on the predictions of theory.	Scientists should be held responsible for the harm their discoveries have caused, e.g., pollution and nuclear weapons.	A scientist should not allow preconceived theoretical ideas to influence observation and experimentation.	A theory is a logical construct of facts and hypotheses that attempts to explain a range of natural phenomena and that can be tested in the natural world.
A theory is what scientists strive for: a large body of continually refined observations, inferences, and testable hypotheses.	Scientists in one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective.	A phrase such as “Many scientists believe...” misrepresents scientific inquiry because scientists deal in evidence.	The scientific method should be followed in all fields of study.
Theory and observation interact. Each contributes to the other: If theory without observation is empty, then observation without theory is blind.	Science builds on what has gone on before and refines its conclusions, but scientific work does not result in infallible propositions, such as the word “proof” implies to a nonscientist.	Unless an idea is testable, it is of little or no use; thus, scientists attempt to convert possible explanations into testable predictions.	Observation is central to all of science, i.e., seeing is believing.
Funding influences the direction of science by virtue of the decisions that are made on which research to support.	Science is never dogmatic; it is pragmatic—always subject to adjustment in the light of solid, new observations.	Science is one of several powerful ways of knowing and understanding the natural world, however, some matters cannot be examined usefully in a scientific way.	Science is always changing and therefore is not very reliable.

Phase 2. Examination of a new set of statements. In this phase, you will examine the statement as in Phase 1, then pick your top two statements or the two with which you strongly agree from your set. At this point, your set should have at least one of each sticky note color. (Participants can also choose one of their top two statements from their own set.) Then, you pick the top two statements from your set. These two statements may be one or two from other members or from your own set.

Phase 3. Group examination of the eight statements on the Jamboard. In this phase, you and other group members will deliberate and decide on the two most important statements about science. Then, discuss among your group the reason why you chose those statements. Finally, create your own set of NOS-related ideas to share with the group. There should be only two statements left on your Jamboard.

PD Session 3

The final PD session engaged participants in an online version of “Mice, Men and Scientists” (Bell, 2008) activity to reinforce sociocultural and subjective NOS aspects. During this session, we explicitly directed the participants’ attention to their varying responses to the

ambiguous images despite looking at the same sets of pictures. We describe the details of the implementation below.

Ambiguous Images: “Mice, Men and Scientists” (Bell, 2008, p. 222)

Although not new, the use of these images has successfully elicited participants’ perceptions, interpretations, and prior knowledge (Bell, 2008), which promotes and improves understanding of subjective and sociocultural NOS (Librea-Carden 2021; Librea-Carden et al., 2023a). We used the images in “Of Mice, Men, and Scientists” (original images from Bugelski and Alampay, 1961) activity in Bell (2008, p. 222) to help participants reflect on scientists’ diverse perceptual frameworks influencing the construction of scientific ideas. The following are details of the implementation.

In this activity, participants examined images to draw their attention to subjective and sociocultural NOS as a group. We modified Bell’s (2008) activity by implementing it online, where images were shown on a PPT instead of using paper and a pen. We showed a series of images in two different sets; first, we showed set A (Fig 5A). Then, we asked them to describe the last image in the row from left to right. We repeated the same procedure, but this time, we used a different set of images (Fig 5B). After examining both sets, we asked them to use the “raise hand” button on Zoom to share what they saw in the last image. A “think-pair-share” followed to discuss their perceptions of the image and their reasons for their perceptions. The exchange of ideas among the participants attracted attention to how the different experiences, imagination, and science background of the individuals influenced their perception of the image. During the group discussion, we reiterated that scientists’ interpretations may be influenced by their different perceptual frameworks and cultural backgrounds. We also describe how society and political contexts can impact their work and vice versa. Finally, participants completed a post-NOS survey (see assessment section below).

Figure 5

NOS Images

First Set of Images (A). Drawings of human faces

Look at the image from left to right. What is the 5th image? Regardez l'image de gauche à droite. Qu'est-ce que la 5^{ème} image ?

انظر إلى الصورة من اليسار إلى اليمين. ما هي الصورة الخامسة؟



Image source: Bell (2008), p. 222.

A

Second Set of Images(B). Drawings of animals

Look at the image from left to right. What is the 5th image? Regardez l'image de gauche à droite. Qu'est-ce que la 5^{ème} image ?

انظر إلى الصورة من اليسار إلى اليمين. ما هي الصورة الخامسة؟



Image source: Bell (2008), p. 222.

B

Assessment of NOS Understanding

We used the Arabic version of the *Student Understanding of Science and Scientific Inquiry Survey (SUSSI)* questionnaire (Al-Sogair, 2019), which was originally published in English by Liang et al. (2006). The SUSSI was used to assess the pre-, mid-, and post-NOS understanding of the participants (for details of the analysis and results, see Librea-Carden et al., 2023b). NOS understanding was classified as “informed,” “transitional,” and

“alternative.” An “informed” NOS understanding indicates an accurate understanding of the currently accepted scientific views. For example, a participant explained that the differences in their cube observation may be similar to how scientists observe their findings. He said, “Science involves the community of different people, taking into account everyone’s reasoning.” He also added that these findings may change because “science is innovating with technology; it is very important to understand new trends making science information more accurate.” Both statements illustrate the “informed” understanding that science, though based on empirical evidence, may also be influenced by individual perceptions and that, additionally, scientific knowledge is not an absolute truth, as it can change with new evidence. A “transitional” understanding indicates that the science view of the participants has more details aligned with the currently accepted science views than those with an “alternative” understanding of NOS. For example, understanding that society impacts science but without details as to how science may also impact society is a ‘transitional’ view. The emphasis on the use of “the” scientific method and experimentation in scientific investigation is considered a “naïve” view of the use of multiple methods in scientific investigations.

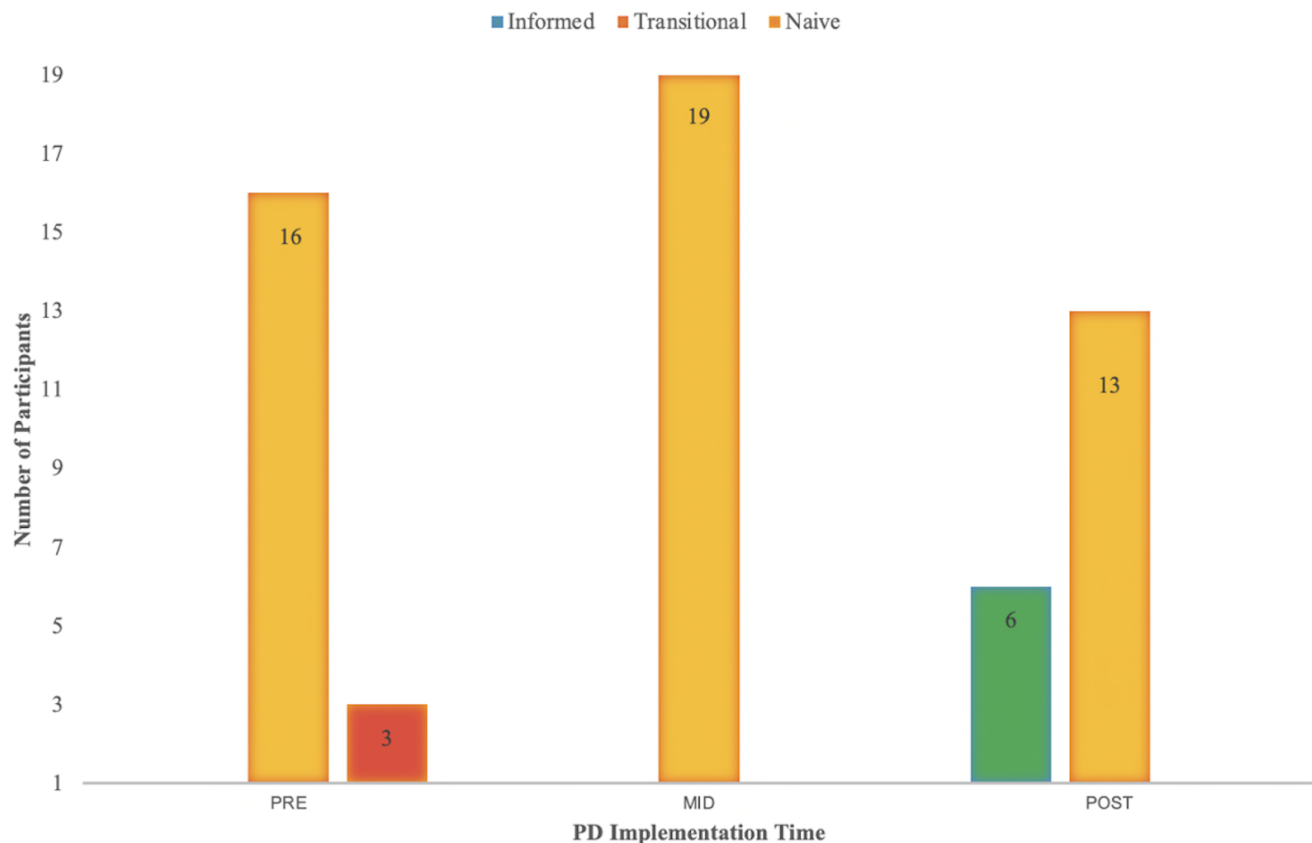
Results of the Implementation

Impact of Online NOS Activities on Participants’ Change in NOS Understanding

Before the oTPD, no one had an “informed” NOS understanding, and three had a “naïve” understanding. Post oTPD, six participants had an “informed” understanding, and no one had a “naïve” understanding (Figure 6).

Figure 6

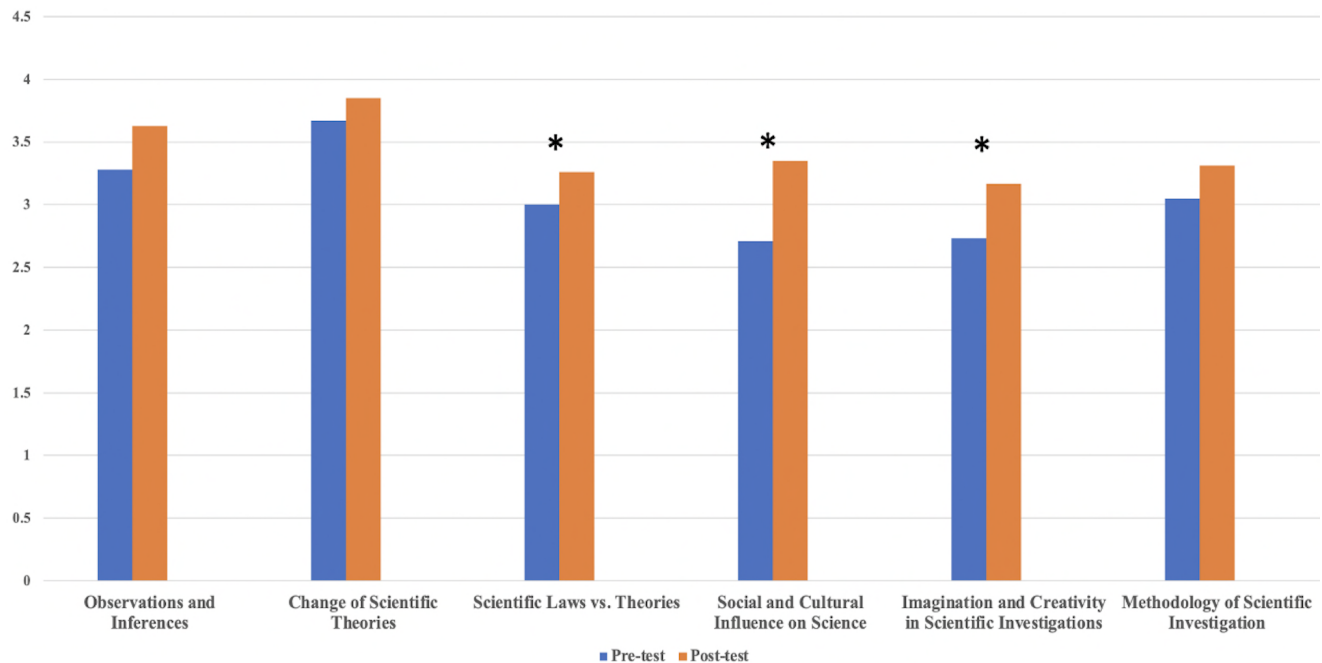
Pre and Post NOS Understandings



Although most retained their transitional understanding of NOS, the participants showed a statistically significant change in sociocultural ($p = .005$) creativity ($p = .031$) and understanding of theories and laws ($p = .043$), with sociocultural showing the most distinct change among the three aspects of NOS (Fig 7). The following section describes the findings on the impact of specific activities on participants' NOS understandings. Each activity addressed specific NOS learning outcomes (see Table 1).

Figure 7

Participants' Pre-Post Test Using SUSSI



*significant differences

Myth or Truth Zoom Poll Assessed Initial NOS Understanding

This activity aimed to introduce NOS ideas to participants. In general, most of the participants (n=19) did not agree with the following statements: 1) “Scientific laws and other scientific ideas are absolute” (61%). 2) “Experiments are the principal route to scientific knowledge” (57%). 3) “The scientific method is universal.” (52%), 4) “Scientists are particularly objective (26%)”. These results, particularly the overwhelming number of participants who agreed with the last statement, prompted us to emphasize creative NOS and the use of multiple methods in scientific investigation. Thus, we implemented the following activities.

Inquiry Cube Activity Reinforced Observations and Inferences, Multiple Methods in Scientific Investigation, Creativity and Tentativeness

The “inquiry cube” activity reinforced participants’ ability to make observations and inferences and promoted the use of other methods of inquiry other than experimentation. It also drew attention to different ways of interpreting what was at the bottom of the cube. During the implementation, we provided participants with opportunities to share their different observations and conclusions about the cube and to critique each other’s arguments. The observations of the participants about the cube led to inferences about what was at the bottom of the cube, including: “even numbers are shaded,” “odd sides are not shaded,” and “the numbers 1, 3, 4, 5, and 6 are visible.” Approximately half the time, someone explained that the opposite of 1 is 6, $1 + 6 = 7$, and the opposite of 3 is 4, which adds up to 7. At the end of the activity, there was a good agreement on what was at the bottom of the cube. To

demonstrate that scientists may agree but may not be completely sure, we did not show the bottom of the cube. Participants reviewed and shared their responses to “How is this different from what scientists do?” One of the participants associated the experience with how scientific knowledge can be revised and stated: “The idea is like reconstructing the science of science, taking into account the observations we are making and following scientific reasoning.” Another participant also said, “Scientists make deductions and interpretations of their own and the observations that they make.” The activity also helped the participants reflect on the use of “the” scientific method. During our discussion, the participants shared ideas that led to an understanding that the construction of scientific explanations does not necessarily need to follow “the” scientific method, as they experienced during the activity. One said: “There are many scientific methods; scientists may use probabilities to draw conclusions as we did in the activity.” Furthermore, participants acknowledged that “finding relationships between the numbers on the faces of the cube did not require experimentation, but more time for observing and thinking.”

NOS Jamboard and Ambiguous Images Activities Emphasized Sociocultural and Subjective NOS

The NOS Jamboard activity was implemented to further explore NOS understandings and represent science as a social activity. The top selected statements of the participants include a) “Science is one of several powerful ways to know and understand the natural world. However, some matters cannot be usefully examined in a scientific way” (consistent with NOS ideas); and b) “Funding influences the direction of science by virtue of the decisions that are made on which research to support” (consistent with NOS ideas) (Cobern & Loving, 2020, pp. 218-220). These selected statements adhere to current reformed science understanding. Finally, participants shared their own sets of NOS-related ideas. These included a) “Science involves “collaboration,” “group discussion,” and “comparing work before drawing conclusions”; 2) “I share the belief that science is participative. Each person can participate differently and have a different viewpoint, but also important is to get along and reach a common agreement”; and c) “Scientists reach an agreement based on data and evidence.”

The last set of activities, the “ambiguous images,” elicited the diverse views of the participants. When the images were shown (Figure 5), participants described them differently, including a “caricature of a man” and “not necessarily a man.” After sharing their perceptions, we asked them to share the reasons for their varying responses. The participants explained that repeated exposure to the image influenced their view of the image. One said, “As we saw the image for the third time, we were influenced by what we saw previously.” Another participant explained, “We were influenced by the information given by the second image with the outline.” Similarly, participants described how their perspectives influenced their perception of the image for the second set of images (Figures 5A and 5B). Some of the responses include: “It is the same image as the first image shown,

but our imagination influenced us.” “It’s the same image, but we are influenced by the previous images on the left.” We also asked them if they had other perceptions of the fifth image other than a “man” or a “mouse.” The following were the responses: “I cannot see anything new because I am set with the image of the mouse or the previous image. I cannot change my mindset.” “I see the characteristics of the mouse, I see the ears, the eyes, and the tail, so I can’t change my perceptions. I have set that in my mind.” “Right now, I don’t see a mouse, but with additional information, parameters, I could see something different.” “Right now, the image of the mouse has synchronized with the idea of the mouse and so it’s linked to the brain.” “Now that we have set the theory about the mouse, we set an understanding that this is our probable inference and a good observation.” During the debriefing session, participants share their thoughts on how the ambiguous activity may be similar to how scientists make sense of the data. They said that “science does not provide one absolute answer; there can be different points of view.” “Science involves community, different people and whose views and reasonings can be accounted.” “Science is innovative with the use of technology, and our preservice teachers need to understand what this innovation has to offer to science, and how it can make scientific information accurate.” “Observation of the image can hardly be objective.” At the end of the session, we emphasized that scientists may have different interpretations and conclusions from the same data because of their prior knowledge, experiences, educational background, perceptual frameworks, culture, and traditions; thus, similar to their varying responses to ambiguous images despite looking at the same image.

Discussion

Change in NOS understanding Through the NOS Online Activities

The overall improvement in participants’ understanding of the Nature of Science (NOS) during our Morocco implementation is encouraging, particularly given that many had no prior knowledge of NOS at the start of the online professional development (oTPD). For instance, the enhancement in participants’ understanding of the sociocultural aspect of NOS is a promising outcome, especially considering previous findings that suggest sociocultural NOS can be resistant to change (e.g., Mesci & Schwartz, 2017). This improvement can be attributed to the implementation of the ambiguous image “Of Man, Mice, and Scientists,” which emphasized the influence of culture, personal experiences, and beliefs on science. Participants recognized how their unique backgrounds influenced their views on science.

The significant change in participants’ understanding of the creative aspect of NOS aligns with findings from other studies (e.g., Akerson et al., 2000; Bell et al., 2016; Herman & Clough, 2016; Librea-Carden et al., 2021). This positive outcome is noteworthy, considering that most participants initially perceived scientists as particularly objective and adhered strongly to experimentation. This shift can be attributed to the “inquiry cube” activity, which explicitly debunked the myth of “the” scientific method and the necessity of experimentation.

In this activity, participants collected and analyzed data without following a step-by-step scientific method or conducting experiments to answer the question, “What is at the bottom of the cube?” Additionally, participants engaged in a group discussion after the NOS Jamboard activity, where they constructed new NOS-related ideas, reinforcing their understanding of the creative aspect of NOS.

Although other aspects of NOS did not show significant change, it is important to consider the relatively short duration of the PD intervention. Overall, the improvement in participants’ NOS understanding is a promising indication of the potential for online PD to enhance NOS understanding among international participants.

On PD Implementation

Online professional development for teachers offers access to a wide range of learning opportunities given the convenience of location and time (National Research Council, 2007) and the geographical location of participants, such as those in Morocco. Our study allowed Morocco participants to engage in NOS-PD at their preferred times and locations. This is crucial for international PDs considering the challenge of time, distance, and cost, as Li et al. (2023) reported. These authors also emphasized that effective online PD requires the availability of technical support. To this end, we used video clips to show the “inquiry cube,” providing a practical, reusable, and readily available tool for all participants.

While online PD offers these benefits, synchronous sessions, like those in our study, can reduce flexibility when the PD schedule is fixed. This aspect warrants further investigation, as we did not explore participants’ perceptions of the advantages and disadvantages of our PD. However, contrary to reports about the difficulty of creating real-time communication communities, our online synchronous PD allowed participants to collaborate and share ideas in real time. Considering these reported benefits and limitations, we identified the affordances and constraints of online PD based on our experience as facilitators.

Affordances of NOS oTPD

Our oTPD bridged distant collaboration, as reported in a previous study (Lay et al., 2020). Our sessions encouraged collaboration with our participants and created a digital space that offered ways to access NOS resources for teaching. While previous studies reported that fostering a sense of community may be challenging in oTPD (Li et al., 2023), we encouraged participants to actively share their insights every session, either in a small breakout group session or during the large group discussion. What was most helpful was having a facilitator who speaks French (i.e., participants spoke this language). Furthermore, providing instructions (in English, French, and Arabic) on using the Zoom tools, such as chat boxes and raising hand buttons, facilitated effective communication. It was also interesting that despite the language barrier, our oTPD increased its international network, developing a

global community of peers sharing common professional learning goals. In fact, some of the participants expressed interest in providing a version of the NOS workshop for their colleagues.

Constraints of NOS oTPD

However, we also identified its limitations as mostly logistical and technical issues. Some participants have difficulty connecting to the internet at certain times and locations (i.e., during PD sessions). These technical issues with devices delay communication and may be aggravated by a lack of digital competency (Bragg et al., 2021). Due to the synchronous format of our oTPD and time zone, the time for interaction and reflection was limited. For example, it was difficult to extend the time for reflection because it was already late at night for our participants. Although flexibility in location is advantageous for oTPD, it could also be an obstacle. For example, some participants were attending the oTPD in the common area of their house with background noise that interfered with focus and participation. To address these challenges, we also offer recommendations for future implementation in the following section.

Future Implementation of NOS oTPD

We hope to make this virtual activity transferrable to science methods courses and international contexts. For science methods courses, we recommend the following to successfully implement the activities: 1) administer the Poll survey at the beginning of the class. This survey is crucial for initially assessing students' understanding of NOS and targeting NOS aspects to emphasize during the session. However, this should not replace open-ended questionnaires such as *SUSSI* to assess NOS views. 2) When implementing the "inquiry cube" activity, there should be a link to the video of the cube for each group in the breakout room. If possible, join each breakout room to listen to the group discussion.

For the international audience, we recommend conducting a survey before the oTPD on their online experience, including Zoom competency, accessibility to internet and internet devices, and other necessary digital accommodations. This survey will help address potential technical issues and, therefore, maximize participation. It would be helpful to coordinate with one of the potential participants who can help with technology issues. Also, consider offering an asynchronous activity to address the time constraint during the synchronous oTPD, especially if the time zone is challenging.

Conclusion

Our work with Moroccan teachers suggests positive impacts of the series on participants' understanding of NOS. The activities implemented in this online synchronous teacher professional development (oTPD) represent an initial effort to expand professional learning

opportunities to regions like MENA, where NOS education may be limited. The research underscores the benefits of enhancing the accessibility of oTPD for educators, emphasizing the importance of designing such learning opportunities, as described in our oTPD.

There remains considerable work ahead to improve NOS understanding in international contexts. Fundamental to this effort is ensuring that educators possess accurate and comprehensive pedagogical knowledge of scientific concepts and the construction of scientific knowledge (Librea-Carden et al., 2023b). Educators play a pivotal role in achieving this goal, beginning with the provision of well-designed and accessible NOS professional development for international participants. Our implemented NOS oTPD provides empirical evidence of the potential effectiveness of online NOS professional learning globally, as evidenced by our findings. Importantly, our online PD contributes to the limited empirical research on online NOS-PD, demonstrating significant improvements in participants' NOS understanding despite the brief intervention period. While acknowledging constraints, we argue that the benefits outweigh the limitations of oTPD, at least in our case. Nevertheless, this work underscores the ongoing need for further exploration and refinement of NOS oTPD design, especially in regions with limited resources and research on NOS education. Moving forward, we are committed to developing strategies that bridge these gaps and harness the potential of online PD to enhance access to continuous professional development for science educators.

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Supplementary Materials

[Zoom Poll Instructions](#)

[Inquiry Cube Video Clip](#)

[NOS Jamboard](#)

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