Promoting Understanding of Several Elements of Nature of Science Using an Analogy: A Tangram Activity

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Abstract

Developing a proper view of the nature of science (NOS) amongst teachers and students has been the goal of science education for decades. This article discusses an innovative activity designed for training preservice science teachers on NOS. We endorse an approach according to which several aspects of NOS can be explicitly discussed and explained. This activity is an extended version of a tangram activity introduced by Choi (2004). Aside from introducing NOS elements covered by Choi, our tangram activity also introduces the following elements: (1) theories are valid products of science, (2) the role of subjectivity and bias in science, (3) the importance of scientific community in science, (4) prediction is part of science, and (5) creativity and imagination are important in science. The activity can be used decontextualized (i.e., as a stand-alone lesson) in science methods classes, but it also has high potential to be contextualized within content related to the history of science. In this article, we provide procedures for using an analogy activity (the tangram activity) and explain how to connect each part to NOS elements. This activity was tested successfully in several science methods courses, a NOS course, and two professional development workshops.

Introduction

For more than 100 years, learning about the nature of science (NOS) has been advocated as a part of the study of science (McComas & Clough, 2020). NOS is “a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors” (McComas et al. 1998, p. 4). Knowledge of NOS increases scientific literacy by developing individuals who understand scientific issues and are able to use this knowledge to make informed judgments and decisions (Hazen, 2002).

Standards such as the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) and efforts within the science education community (e.g., Lederman, 2007; McComas, 2020) have provided some guidance about what NOS skills should be targeted in instruction. However, the goal is to improve science teachers’ knowledge of NOS and help them to reflect this knowledge in their teaching through engaging activities (Melo & Bächtold, 2018). To reach this aim, science educators suggest that science teacher preparation programs should provide preservice science teachers (PSTs) with knowledge of NOS and methods of teaching it in the classroom (Nouri et al., 2021). This is especially needed because science teachers themselves may not hold clear ideas about NOS to include in their teaching agenda

(Morrison et al., 2009; Dorsah, 2020). Research supports the positive impact of NOS-related activities in helping teachers to develop NOS-related content knowledge (Cofré et al., 2018; Cofré et al., 2019). Aspects of NOS that are learned and internalized through the context of activities, narratives, discussions, historical case studies, and science content have an increased chance of being used in the K-12 classroom (Wahbeh & Abd-El-Khalick, 2014). This shows the importance of introducing targeted and effective activities in teacher preparation and professional development programs. The most frequently used "decontextualized NOS activities," as cited in previous research, are Black Box, Tricky Tracks, Fossil Activity, Pattern Cubes, and File Folders; most of these activities were introduced by Lederman and Abd-El-Khalick (1998). These activities cover some aspects of NOS, including observation, inference, and creativity.

The tangram activity discussed here uses five pieces of the famous tangram puzzle with specific guidelines to analogize several elements of NOS. The main idea of this activity stems from a NOS activity designed by Choi (2004) called "The Extra Piece," which is available online (see Appendix A for a summary of the activity). In our tangram activity, changes in implementation were made to cover more elements of NOS and make the activity more interactive. In Choi's (2004) activity, everyone follows the same instructions. In our tangram activity, different groups use different assumptions and reach different conclusions, which provides lots of opportunities to simulate what scientists do. The purpose of this activity is to encourage PSTs to think about NOS and learn about different NOS elements.

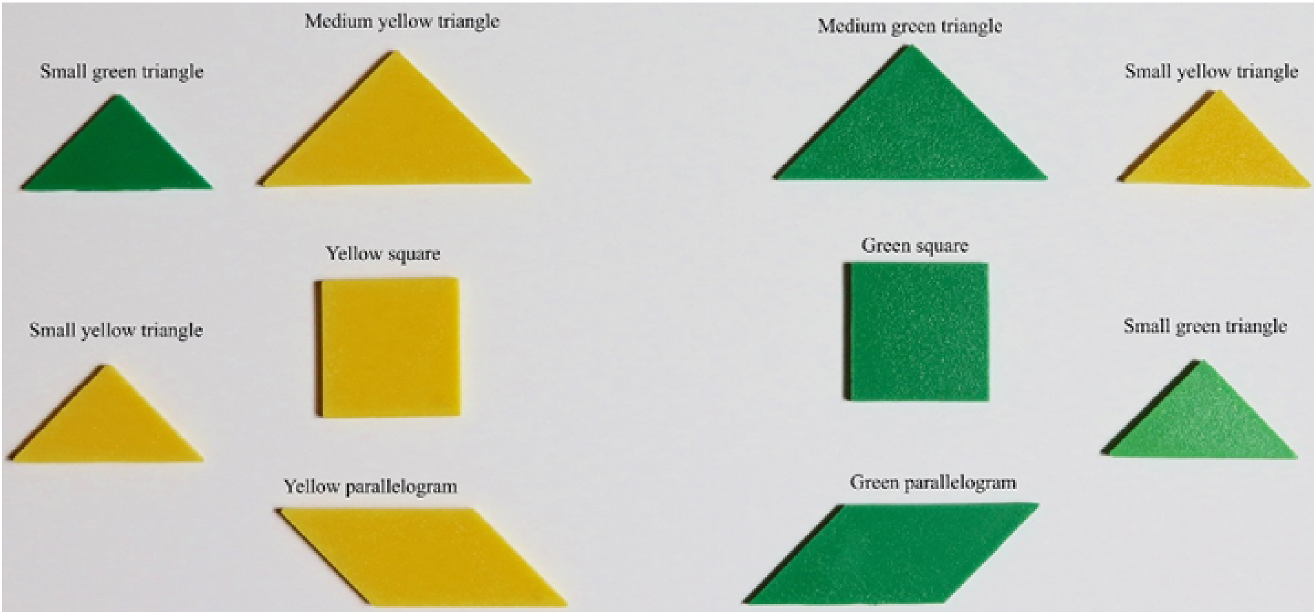
The authors have used this activity effectively in several science methods classes, a NOS class, and two inservice professional development workshops. Although this tangram activity is promising, we would like to emphasize that no single NOS teaching strategy will suffice for teaching NOS elements.

Procedure

In this section, we first explain the activity for use in the classroom. Later in Step 4, we will explain the tangram's connection to NOS in detail. A tangram is a famous puzzle in which a player can complete the puzzle by moving and rotating seven shapes, including one square, one parallelogram, two small triangles, one medium triangle, and two big triangles. In our activity, we use five pieces of the tangram puzzle (the two big triangles are omitted). Figure 1 depicts all the pieces needed for this activity, and each piece is labeled.

Figure 1

All the Pieces Used in the Activity



Information on these pieces and how they should be distributed among groups at each step are described in Table 1. PSTs should work in groups to complete this activity. At least three groups are needed, but group sizes and the number of groups with the same conditions will depend on the number of PSTs. In classes with large numbers of students, it is possible to have two of each group.

Table 1

Information About the Specific Puzzle Pieces at Each Step of the Activity

	Step 1				Step 2
Group	Piece 1	Piece 2	Piece 3	Piece 4	Piece 5
Group 1	Small yellow triangle	Small green triangle	Yellow square	Yellow parallelogram	Medium yellow triangle
Group 2	Small yellow triangle	Small green triangle	Green square	Green parallelogram	Medium green triangle
Group 3	Small yellow triangle	Small green triangle	Yellow square	Yellow parallelogram	Medium yellow triangle

All groups receive worksheets to follow and fill in during the activity (see the worksheet in Appendix B). They also receive written guidelines on how they should complete their puzzle. We called these instructions that each group has received “assumptions,” which are in Table 2. All groups should put together the pieces of the puzzle in such a way that the final product achieves maximum symmetry, either a square or a rectangle. However, based on the assumptions, Group 1 is not supposed to include a parallelogram, and Group 2 is not supposed to include a square when solving the puzzle.

Table 2

Assumptions to Guides Each Group in Solving the Puzzle

Group	Assumptions
Group 1	1. Your puzzle should achieve maximum symmetry (the final shape of the puzzle is a square or a rectangle). 2. Only use triangles and squares.
Group 2	1. Your puzzle should achieve maximum symmetry (the final shape of the puzzle is a square or a rectangle). 2. Only use triangles and parallelograms.
Group 3	1. Your puzzle should achieve maximum symmetry (the final shape of the puzzle is a square). 2. You can use all the pieces.

PSTs are provided rules for solving the puzzle, found in Table 3. For example, PSTs may reach the conclusion that to make a square with the given pieces, they need a new piece. However, according to the rules in Table 3, this new piece cannot be identical to a piece that they already have.

Table 3

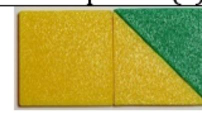
Rules for Arranging the Puzzle

Game tips
1. To complete the puzzle, you may need to put away a piece or predict and get a new piece. 2. The new piece that you are predicting is only allowed to be yellow or green. 3. When you are predicting, make sure that all the puzzle pieces are unique (you cannot have two pieces of the same shape, size, and color).

Step 1: Putting the Puzzle Pieces Together Based on the Assumptions and Rules. All pieces except the fifth piece should be handed out to PSTs with the explanation that they are playing the role of scientists and that the puzzle pieces represent the same data available to all the scientists. PSTs start to arrange the pieces in their groups based on the assumptions (see Table 2) and rules (see Table 3) provided. PSTs are also asked to draw all possible arrangements on worksheets and predict the shape and color of a piece they need to complete their puzzle if they are not able to complete it with the pieces they already have. In Table 4, we have included the final arrangements of the puzzle for each group based on what we have seen in our classes, with the instructor making sure the students are following the assumptions and rules. Remember that the assumptions each group has are different, so they will form different final puzzles.

Table 4

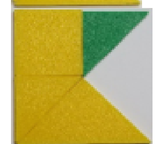
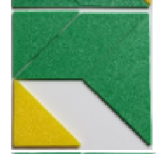
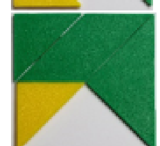
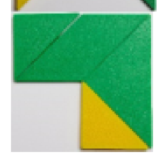
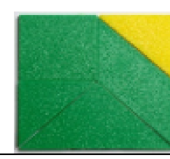
Explanation of Possible Products of Each Group and Their Final Puzzle(s) in Step 1

Group number	Explanation	Final puzzle(s)
Group 1	Group 1 omits the yellow parallelogram because of the lack of compatibility with one of their assumptions and constructs the puzzle depicted here.	
Group 2	Group 2 omits the square because of the lack of compatibility with one of the assumptions and constructs the puzzle depicted here.	
Group 3	Group 3 is not able to build a square or rectangle with the available pieces. Through discussion amongst themselves or with instructor guidance, they may reach the conclusion that they need one more piece to build the square. There are three possible solutions. In this stage, we ask Group 3 to introduce their predicted pieces. Based on the rules, the new piece should be unique in either color or size. Three possible predictions are a yellow parallelogram (i.e., 3a), a medium green or yellow triangle (i.e., 3b), or a yellow square (i.e., 3c). The instructor should make sure that they are predicting all three possibilities.	3a  3b  3c 

Step 2: Adding a New Piece to the Puzzle. In Step 2, the fifth piece, a medium triangle (yellow for Groups 1 and 3 and green for Group 2), is given to the groups with the explanation that a new scientific discovery has been made. PSTs are asked to decide what they want to do with this new piece. They can choose to ignore this new data or somehow incorporate it into their puzzle based on their given assumptions. They should draw their possible solutions and predict the new piece that they need if their puzzle is incomplete with the available pieces. The final puzzle or puzzles for each group are explained and shown in Table 5.

Table 5

Explanations of Possible Products of Each Group and Final Puzzle Shape(s) in Step 2

Group number	Explanation	Final puzzle(s)
Group 1	Group 1 cannot make a square with the existing pieces, so there are two possibilities for this group: • Putting all four pieces together and making a rectangle (i.e., 1a). • Through discussion amongst themselves or with instructor guidance, they may reach the conclusion that they need one more piece to build the square to obtain "maximum symmetry." There are three possible solutions. Because predicting a parallelogram is against their assumptions (i.e., 1b), only two shapes are acceptable (i.e., 1c and 1d). In this stage, we ask Group 1 to introduce their predicted pieces. Two possible predictions are a green square and a medium green triangle.	1a  1b  1c  1d 
Group 2	Group 2 cannot make a square or rectangle with the existing pieces. So, there are two possibilities for this group: • The group concludes that the existing model with three pieces (i.e., 2a) is completely compatible with the assumptions, and because the new piece (i.e., the green triangle) does not match the arrangement of the puzzle and interrupts the existing order, they consider the new one an extra piece. • Through discussion amongst themselves or with instructor guidance, they may reach the conclusion that if they change their puzzle to include all four pieces, they need one more piece to build the square. There are three possible solutions, amongst which only two are acceptable (i.e., 2b and 2c), because predicting a square is against their assumptions (i.e., 2d). In this stage, we ask Group 2 to introduce their predicted pieces. Two possible predictions are a yellow parallelogram and a medium yellow triangle.	2a  2b  2c  2d 
Group 3	For Group 3, because the new piece (i.e., medium green triangle) was already predicted in the previous step, they can use the new piece to complete the puzzle.	

Step 3: Reporting the Results. In this step, groups report their results to the class. The instructor explains, "As a group of scientists, the plan was to make a model, and now it is time to report your results to the scientific community." They are asked to draw their final puzzles on the board and explain their predictions and any pieces that they did not include in the model.

Group 3 begins by sharing their complete model with the class. Group 2 reports their final predictions: that they need either a yellow parallelogram or a medium yellow triangle to solve their puzzle. They also report that they have a green square as an extra piece. Group 1, on the other hand, needs either a medium green triangle or a green square, and they have a yellow parallelogram as an extra piece. After each group's explanation, the instructor draws the attention of Groups 1 and 2 to the pieces that they need (if they have not noticed this themselves). Group 1's extra piece (i.e., the yellow parallelogram) is what Group 2 needs to complete the puzzle. Similarly, Group 1 needs Group 2's green square to solve their puzzle. These two groups can exchange pieces to complete their puzzles. Then, the following question is raised by the instructor: "You'll notice you all made squares in the end, but you didn't all use the exact same pieces to do so. Why was that the case?" It is expected that PSTs will reply that the different results happened because one group didn't use a square and the other group didn't use a parallelogram. In responses to this answer or similar ones, the instructor should direct the discussion toward similarities and differences between the given assumptions for each group.

Step 4: Connecting the Activity to the Nature of Science (NOS). At this step, the instructor needs to explain in greater detail how the tangram activity can work as an analogy to teach NOS. Instructors have some options to make the process more student-centered. They can provide the aspects of how science works (see Table 6) and ask PSTs to connect these aspects to the tangram activity. They also can give PSTs one of the two columns of Table 6 and ask them to provide the other column. Students could write this individually, in groups, or it could be accomplished through oral discussion. Table 6 summarizes similarities between the activity and NOS. The following sections include explanations of the links between NOS elements and the tangram activity.

Table 6

Connecting Aspects of the Tangram Activity to Aspects of How Authentic Science Works

Aspects of the classroom activity	Aspects of how authentic science works
Student group members	Scientists in the research groups
Puzzle pieces	Data that scientists can access
Assumptions	Expectations in the scientists' minds
The complete puzzle	A theory in science
All students' groups together	Scientific community
Reporting results	Exchanging results in the scientific community

The tentative nature of science. Scientific ideas may change in light of new discoveries and evidence. This element is emphasized in NGSS's discussion on the nature of science in Appendix H: "Most scientific knowledge is quite durable but, in principle, is subject to change based on new evidence and/or reinterpretation of existing evidence" (NGSS Lead States, p. 99). In Step 1 of the tangram activity, PSTs in Groups 1 and 2, after omitting the piece that conflicted with their given assumptions, arranged their pieces to build a rectangle. In Step 2, by receiving new data, Group 1 was able to add it to the previous puzzle and be satisfied with a longer rectangle. Similarly, in science, new data may fit a current theory and strengthen it, or new data may lead to a small modification in the theory without fundamentally changing it. On the other hand, Group 2 had two options: (1) ignore the new data or (2) give up their previous puzzle (i.e., a rectangle) and change it to a square. Comparably, in science, scientists sometimes ignore the anomalous result or decide to change a theory that does not fit new data. For example, improved technology and an improved understanding of the situation made it possible for Thomson to improve upon and reject Hertz's experimental results about the cathode ray (Chalmers, 1999).

Theories are valid products of science. In science, we use existing data and evidence to explain how a phenomenon operates, and we call this explanation a "theory." These explanations are well-tested and widely accepted. When a new discovery happens in science, this new data can be supported by an existing theory and either strengthens the theory or leads to a modification of it. According to NGSS, scientific theories are based on a body of evidence developed over time. Through our tangram activity, we want to show characteristics of a proper theory that predicts new data. PSTs would learn that sometimes scientists must modify or discard the previous theory upon new data. The following explanation from the tangram activity clarifies these connections. In Step 2 of the activity, the groups encountered new data. Almost all groups first tried to add a new piece without changing the puzzle they made in step 1. However, in some cases, this was not possible. For PSTs in Group 1, two conditions could have occurred: (1) This group could have hypothesized a rectangular model and built a longer rectangle by adding the new piece to the previous puzzle (i.e., Table 5, 1a). (2) The same group might have concluded that in order to achieve maximum order and symmetry, they should preferably construct a square (i.e., Table 5, 1b, 1c, or 1d). In this situation, Group 1 could build the model in a way that had the ability to predict a new piece. For Group 2, the new piece caused disarray because their model had no place for this new piece (data). Therefore, there were two possibilities. This group could have kept their entire rectangular model, which was compatible with their assumptions, and ignored the new piece for the benefit of keeping the model (i.e., Table 5, 2a). Alternately, they might have decided that the rectangular model was now inadequate because it ignored a piece and was less symmetrical than a square. In this situation, PSTs (i.e., scientists) might put aside the rectangular model (i.e., an old model or theory) in favor of novel evidence and build square-shaped models (i.e., a new model or theory).

Generally, if there is some sort of coordination between the various components of the theory and it answers many of the available questions, scientists avoid changing the entire framework and adopt minor changes. However, new evidence may be inconsistent, and consequently, minor changes to the model may continue to the point where the model is no longer responsive to new data and evidence. In this situation, the scientific community may decide to replace the existing theory with a new one. This may lead to great advances and even scientific revolutions (as in the case of Ptolemy's model and Aristotelian views of motion).

The role of subjectivity and bias in science. Prior knowledge, assumptions, and biases in scientists' minds may affect their approaches. As stated in the NGSS, "scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings" (NGSS Lead States, 2013, p. 100). The theory-laden nature of science means that scientists look for evidence that would confirm their working model. We deliberately gave the groups different assumptions to let them recognize that different assumptions may lead to different results (i.e., rectangle vs. square) or the same result with a different arrangement of pieces (i.e., square frameworks with different pieces). In Step 1, Groups 1 and 2 made a rectangle, but Group 3 ended up making a square because different assumptions led to different results. Comparing the first layouts of Groups 1 and 2 in Step 1 (see Table 4), the first assumptions made by the two groups were common, which led to the final form created by the two groups being the same. However, the differing second assumption led them to select only some part of the available data, and as a result, their puzzle pieces were different (i.e., same result, different pieces). The instructor can emphasize that in science, scientists focus on data that make sense given their assumptions, and they design experiments that are likely to provide data that will be comprehensible, given their views. The instructor should also make it clear that, although we provided the assumptions in the activity, in authentic science, these assumptions are in the mind of the scientists due to their own expectations and biases. An interesting example of bias in science is Millikan's report on measuring the magnitude of electron's charge as elementary charge (Institute of Physics, n.d.). He recorded the results of 175 drops; however, he reported the results of only 58 drops, rejecting two thirds of the data. This selective use of data by Millikan based on his presuppositions, clearly shows the role of scientists' bias in scientific works.

The Importance of Scientific Community in Science. "Production of knowledge [in science] occurs collaboratively between various scientists" (Justi & Mendonça, 2016, p. 809), so scientists work within the scientific community to evaluate and contemplate the work of other scientists. According to the NGSS, "the science community validates each theory before it is accepted" (NGSS Lead States, 2013, p. 99). This implies that it is necessary for PSTs to understand the importance of collaboration, reporting, and peer review in science.

In Step 3 of the tangram activity, groups reported their results to others just as scientists report their achievements to the scientific community. During these reports, Group 1 mentioned that they had an extra piece, a yellow parallelogram. This is akin to new evidence (i.e., data) that is unknown to a group of scientists. Meanwhile, Group 2 sought the same evidence and even predicted its features. This interaction, collaboration, and scientific exchange can lead to the advancement of science.

At this point, the instructor can build on the activity and emphasize that the scientific community is an important element in the development of science. Reports, discussions, and internal conflicts amongst members of the scientific community lead to the spread of human knowledge. In addition, the only reference point for judging the value of a theory or model, as well as the only reference for correcting errors in science, is the scientific community. Therefore, although science is tentative, the self-correcting feature of science through the scientific community makes science more reliable and lasting. As a historical example, Heisenberg and Bohr debated with Einstein about the completeness or incompleteness of quantum mechanics; as a result, Bohr came to revise his view and avoid the idea of a perturbation (Bohr, 1958).

Creativity and imagination are important in science. Creativity and imagination play an important role in science, from the kind of questions scientists ask to how they interpret data. According to the NGSS, “scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination, and creativity” (NGSS Lead States, 2013, p. 100).

Whereas most people think scientists just use their creativity and imagination in the initial steps of scientific investigation, the tangram activity shows that it is important in every step. PSTs also used their creativity and imagination in different sections of the activity: trying to put together their pieces and arrange them, predicting all the different possibilities, and recognizing the fact that adding new data may require changing the current framework. Here the instructor should bring PSTs’ attention to the fact that they used their creativity in all of the mentioned steps and connect it to the work of scientists. As a historical example, Kekule was creative enough to connect his dream about a snake trying to bite its own tail to the hexagonal structure of benzene (Okasha, 2002).

The role of trial and error and serendipity in science. Trial and error are fundamental parts of problem-solving, and science is no exception. In addition, luck or serendipity in science is “being able to take advantage of sometimes unforeseen circumstances when they arrive” (Moss et al., 2001, p. 780). The NGSS emphasizes that there is more than one way of doing science: “Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge” (NGSS Lead States, 2013, p. 98). There are many examples in the history of science when scientists have come up with a discovery by chance or by trial and error. Trial and error as one of the features of science can also be discussed with PSTs via this tangram activity because they should keep trying different options and possibilities to eventually find a pattern for solving the puzzle. The role of trial and error is highlighted in the stages where PSTs want to make squares despite the lack of pieces (Step 1 for Group 3 and Step 2 for Groups 1 and 2). The instructor should also make it clear to PSTs that the inductivist approach is just one way of doing science. As a historical example, while investigating uranium, Marie Curie conducted lots of trials to confirm the super-potent radioactivity of uranium (Valiunas, 2012). Measurements had to be repeated many times to make sure no crucial error had been made.

Regarding the role of luck, there are two aspects of this element in the tangram activity. In Step 1, Group 3 (see Table 4) eagerly looks for the new piece, so when they find it by chance (unplanned), they immediately responded to it. In other words, serendipity in science can only be exploited by someone who is looking for something specific. There are many examples of this in the history of science, such as the discovery of penicillin. Comparing Groups 1 and 2, who might unknowingly overlook similar evidence, Group 1 is looking for a green square while Group 2 is waiting for a yellow parallelogram to complete their puzzle. As a result, they can take advantage of these unforeseen circumstances when they arrive.

Prediction is part of science. “Scientific theories provide the foundation on which predictions and hypotheses are built” (Bell, 2009, p. 4). Prediction as a science process skill is widely emphasized by the NGSS; for example, “scientific questions [are] … inspired by the predictions of a model, theory, or findings from previous investigations” (NGSS Lead States, Appendix F, p. 4). Prediction is important in knowing how science works, and its importance can be depicted through our tangram activity.

In Step 1, Group 3 predicted three possibilities for a new piece, and they received one of them in Step 2, which led them to understand the value of a correct prediction. In addition, their correct prediction gave more value to their model. In Step 2, Group 1 had two different options. The first option was creating a rectangle, which seemed to be a complete model. This model was apparently consistent with the existing data and assumptions. The second option was deciding to make a square that needed one more piece to be complete, but a square would have the most symmetry. This raises the question, which of these two models in science is preferable? The second model is more valuable and more acceptable in the scientific community for several reasons. Although part of the model is incomplete and may not already be responsive to some issues, other parts of the model that formulate square shapes are more consistent with the first assumption: “Your puzzle should achieve maximum symmetry” (Table 2). In addition, a model that provides the opportunity to predict possible new evidence and opens a possibility for advancing science is more valuable. Theories and models that have the ability to predict future data are called “progressive” by Lakatos (1970), who also mentioned that such models are preferred in science.

When groups reported their results in Step 3, Group 1 was eagerly looking for a green square and obtained it after Group 2 reported having it. This means that a proper prediction can sometimes lead to mental preparation for scientists to recognize new data (which, of course, is a double-edged sword). As a historical example, Mendeleev and others employed the periodic table to predict the properties of some undiscovered elements. Also, there are examples of cases in which new elements did not fit the expected patterns of the periodic table, which led to confusion (Ben‐Zvi & Genut, 1998).

In this section, we discussed seven important NOS elements that the tangram activity can cover. Instructors can choose all or some of them depending on their goals and the time available. For evaluating the activity, we used a worksheet (see Appendix B) that PSTs should fill out during the activity. This worksheet helps the instructor to recognize whether the groups have followed the steps of the activity correctly. Classroom discussions; reflection papers with specific questions; and Questions 3, 4(c), 7, and 10 from VNOS-D$^+$ (Lederman et al. 2002) can be used to investigate improvement in PSTs’ NOS knowledge. Instructors can also use any other tools that measure NOS elements covered in this activity.

Implementation

As we mentioned in the introduction, this activity aimed to help teachers develop more informed knowledge of NOS. First, the instructors should be aware that considering the following points can lead to implementing the activity more successfully and effectively. To facilitate students' reflections on NOS aspects, the instructor should monitor each group in every step and make sure that they are following the assumptions and rules. If the group members have difficulty with arranging the puzzle pieces, the instructor can provide some clues for them or help them. The instructor should also make sure that each group fills out the worksheets, especially drawing all different possible solutions in their worksheets, so that they can refer to them later. In the Step 3, the instructor should draw the PSTs' attention to the pieces that each group has more or less of, especially if no group pays attention to them. The instructor should also try to make the class discussions as student-centered as possible, particularly in Steps 3 and 4, and allow the PSTs themselves to make connections between the activity and NOS. As one option, the instructor can explain each NOS element and ask PSTs to make connections between the activity and the mentioned element. The inclusion of historical examples can help PSTs make connections between the NOS elements and the activity. Generally, some important points for implementation are:

- Make sure to use just two consistent colors for all groups to avoid confusion.
- Allocate at least 1.5 hours for the activity.
- Group 3 needs more time and help in Step 1, and Groups 1 and 2 need more time and help in Step 2.
- In Step 2, if Group 1 was satisfied with the rectangle, the instructor should encourage them to make the square too.
- The instructor should be aware of all possibilities in advance.

Results

The implementation-specific data reported in this article came from three science methods classes in which the only intervention related to NOS was the tangram activity and a course in which this tangram activity was one of several strategies implemented. A total of 42 PSTs, who had never taken formal courses related to the nature of science, participated in these training courses. To investigate the effectiveness of the tangram activity on PSTs' NOS views, we used classroom discussions, reflection papers, and four items from the VNOS-D^{+} questionnaire. PSTs' discussions and answers were analyzed qualitatively using the thematic analysis method. In general, the results showed that this activity has been successful in covering the desired NOS elements. Here we provide some data obtained from the analysis process. As we mentioned before, after doing the activity, PSTs were asked to connect the tangram activity to NOS elements, and then historical examples related to NOS elements were provided. During classroom discussions, most groups were able to correctly explain the connections between the activity, NOS elements, and historical examples. One group said the following: "Ptolemy's model was not responding to new observations; first ancient scientists tried to keep the model with small justification, but eventually they realized the framework should change like we had to change our framework doing the puzzle."

In the reflection papers, we specifically asked PSTs to answer the following question: "How did the tangram activity help you to recognize how science works and what scientists do?" Table 7 shows some responses to this question and the corresponding NOS elements.

Table 7

Participants' Reflections on How the Tangram Activity Helped Them to Recognize NOS Elements

Sample quotes	NOS elements
"From this activity, I learned that science is subject to change. When new data is introduced, scientists need to leave room for improvement and be willing to share that data with others. We must be aware of our biases and preassumptions because they may get in the way of our interpretation."	Tentativeness, Subjectivity
"I am more impressed with the role of creativity than before. To be honest, previously, I believed it does not have any position in science or maybe a little bit when coming up with a question. Now I see it can play [a] role in every action of scientists."	Creativity
"It was fun to see how new data can change a framework. The part that I liked most was learning what happens in the real world that makes scientists modify or change their idea or their theory. I also recognized how biased I was to a simple puzzle, and I did not want to change it after receiving a new piece, so I guess I understand now why science is subjective."	Tentativeness, Subjectivity, Theories in science
"Our group was the lucky one that received exactly what we predicted. I recognized the role of good prediction as well as chance and luck."	Luck, prediction
"I feel I appreciate scientists even more because I was frustrated with trying three new designs, so when I heard in the class that Edison or Curie tried hundreds of times until reaching the results, I was so impressed."	Trial and Error

The interesting thing we came across was that sometimes PSTs made connections between the tangram activity and authentic science that we did not discuss during or after the activity. For example, a PST made her own conclusion of tangram activity and reflected on it as "I learned there are many different possibilities to reach the conclusion; it does not matter how we reach that; it matters that we reached it."

We also analyzed PSTs' answers to four items from the VNOS-D$^+$ questionnaire that were related to the NOS elements covered by the activity in the following order: Question 3 was used for tentativeness, Question 4c for subjectivity, Question 7 for creativity, and Question 10 for the sociocultural aspect of science. Here we provide some sample quotes from PSTs' answers to these questions. For example, one PST answered Question 10, the sociocultural item, saying: “In order to convince other scientists about their findings, the scientist must report to the scientific community the results of their works and experiments and get the approval, similar to what we did in the tangram activity.” Subjectivity (Question 4c) was one the most important focuses of the activity, and most PSTs mentioned that the role of assumptions is important in science. One PST said, “Scientists have assumptions, and their observations are certainly influenced by their assumptions . . .. Sometimes these assumptions make it possible to look at results that may not matter to others.” As an example of tentativeness in answering Question 3, one PST said:

I do think science changes over time. When new data comes, scientists try to fit it to the existing theory, and if it is not a good fit, they start to doubt the theory, and maybe later with more outlier data, they change the theory or modify it. The same thing that happened to our understanding of who is the center of the universe, the sun or earth, as you told [us].

Regarding Question 7 about creativity, one PST said: “Yes science is creative, and scientists use their creativity in every simple step of their work like what we did doing the tangram.”

Concluding Thoughts

Regarding the importance of NOS and the emphasis given to it in the standards, it is crucial for future teachers to get a sense of how science works along with its characteristics. In this learning experience, we introduced the tangram activity to enhance teachers’ NOS views in various NOS elements. In this activity which includes four steps, five pieces of the famous tangram puzzle are being used as well as some pre-determined rules and assumptions. In Step 1, PSTs put the puzzle pieces together based on the assumptions and rules, and then in the next step, a new piece will add to the puzzle while PSTs should decide how to deal with it. In this step, some groups may lack a piece or have an extra piece. All groups will report their result during the third step, and groups can exchange pieces. Finally, classroom discussions will include connections between the activity and NOS aspects as well as historical examples related to each aspect. NOS aspects that are emphasized in the tangram activity include tentativeness, theories as valid products of science, subjectivity, the importance of the scientific community, creativity and imagination, and the role of trial and error, luck, and prediction in science. All these elements have been recommended both by the NGSS (NGSS Lead States, 2013) and by the science education community (e.g., Lederman 2007, McComas 2020). The tangram activity was successfully implemented with different groups of teachers, and data collected during implementation supports its success in developing NOS knowledge of PSTs in all the emphasized aspects, specifically in subjectivity and tentativeness.

The tangram activity introduced here is inspired by Choi’s (2004) activity called “The Extra Piece.” However, the improvements that we made in the process of the activity enabled the tangram activity to explain several elements of NOS and, at the same time, can be connected to historical examples in more advanced levels. In this activity (unlike in Choi’s activity), not all groups follow the same process. Because they have different assumptions, they do not use the same pieces; therefore, they will end up with different results. It provides lots of opportunities to simulate how scientists work and how they achieve different results despite having the same data. Demonstrating the role of subjectivity in science is one of the most important strengths and innovations of the tangram activity. Collaboration between different groups of scientists and the importance of sharing scientific results inside the scientific community is another innovation of the tangram activity (in Choi's work, only collaborations within a group were considered). Predicting the characteristics of a new piece is another important innovation in the tangram activity. Whereas in Choi's work, the same new piece is given directly to all groups, in the tangram activity, learners can accurately predict the characteristics of the new expected piece and consciously seek to find it. This feature of the activity enables the instructor to address the importance and role of scientific predictions that ultimately lead to the growth and development of science. Moreover, the instructor can draw PSTs' attention to the role of scientists' creativity and imagination in all steps of scientific investigation.

This activity can be used in professional development programs for inservice teachers and in science methods classes for preservice science teachers as a tool for communicating several NOS elements. It also works as a bridge to connect NOS to the history of science. Please notice that the tangram activity is more beneficial for teachers (rather than students) because of its complexity, which is one of the limitations of the activity. If someone wants to implement the activity with students, they may have a hard time predicting new pieces and need extra help from the instructor. Because the activity alone covers several NOS elements, it is worth the time it takes, so we highly recommend including it in the science methods classes or professional development with the aim of covering NOS elements.

Supplemental Files

Appendices-A-and-B-Vesali-et-al.-2021.docx

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