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Research Article

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Turkish and American science teachers' perceptions about science models and modelling

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ABSTRACT

The need for authentic practices such as science modelling in school science has been shown through international assessment scores. Numbers of studies have shown the efficacy of the use of modelling on students' conceptual knowledge and reasoning abilities. However, the international assessment scores have not risen greatly in most countries. Thus, the question becomes are students being taught modelling practices in schools. Research implies that teachers, both pre- and in-service, may lack the expertise to guide students in the usage of models and modelling. This study compares the perceptions of models and modelling in two countries, the US and Turkey, using a qualitative interview research design to determine what differences exist between teachers' perceptions in these two countries since the US scores higher than Turkey on international assessments. The results show that there are few differences in teachers' perceptions of models and modelling between these two countries. The paper concludes with suggestions that are pertinent to science educators in terms of training needs for both pre- and in-service science teachers.

Keywords: models & modelling, multiple representations, science modeling, science teacher education, teacher beliefs

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INTRODUCTION

International studies over the years have suggested that students worldwide need to acquire as well as practice higher order thinking skills in science classrooms (Mullis et al., 2016; OECD, 2016; Schleicher, 2019). Turkey and the US scores have been low and have been classified as level 2 and level 3, respectively. One might infer that low scores on these tests reflect lack of opportunities for students to gain these skills. Implementing classroom instructional practices that engage students in interpretation of scientific data and scientific reasoning through authentic practices may help remediate this problem.

Thus, we must question what is authentic science practice? What do scientists do to make sense of the world? Scientists construct science models that have multiple representations (e.g., diagrams, graphs, mathematical equations, etc.), and use these models to make predictions within what is known as scientific modelling cycles (Gilbert & Justi, 2016; Hestenes, 2010; Kozma, 2003). These authentic modelling practices include the use of inquiry labs where scientists develop lab procedures, collect data, analysis the data and develop scientific models with multiple representations (graphical, algebraic, verbal, etc.) based upon the data. These models with their representations can then be used to make predictions of existing phenomena allowing for further refinement of the model. According to the OECD (2014) results, the use of authentic science such as modelling was rarely if ever used within many countries during primary and secondary schooling.

Studies have shown that the use of science models and modelling has produced conceptual gains across multiple science disciplines secondary science disciplines such as physics (Dori & Kaberman, 2012; Eymur & Capps, 2022; Hestenes et al., 1992; Jackson et al., 2008; Liang et al., 2012; Malone & Schuchardt, 2020; Schuchardt & Schunn, 2016). In addition, modelling-based instruction has also helped students achieve gains in problem solving and metacognitive skills, the usage of multiple representations in scientific reasoning skill and model-based reasoning abilities (Heijnes et al., 2018; Miller & Kastens, 2017; Passmore & Stewart, 2002; Rost & Knuuttila, 2022; Schuchardt & Schunn, 2016; Schuchardt et al., 2008). If scientific modelling has been shown to produce such improvements, one might question why there is not greater usage of models and modelling in science classrooms worldwide given the improvement in student knowledge and skills in all the aforementioned areas.

The answer to the lack of usage of models and modelling in the classroom might be answered by some past research from Brazil, Germany, the Netherlands, and the US that implies that in-service teachers in these countries have limited understanding of science

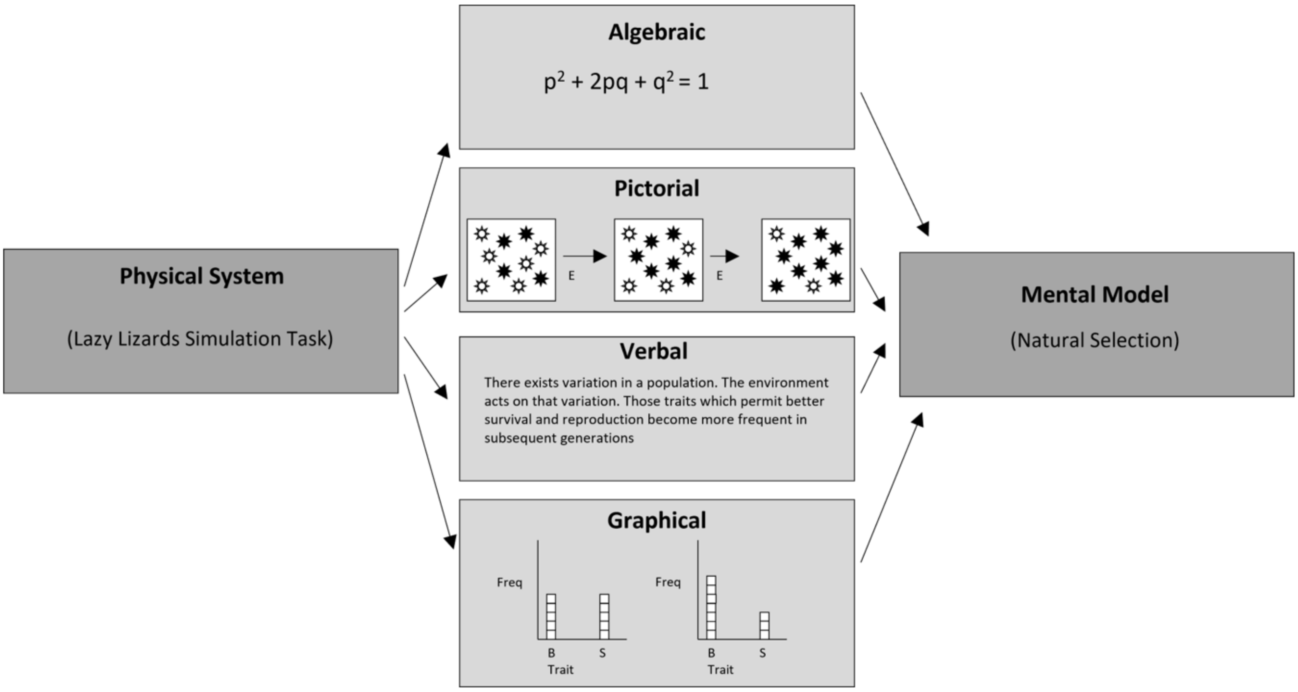

Figure 4. Scientific model representations for natural selection model (adapted from Dukerich, 2015)

modelling (Berber & Guzel, 2009; Henze et al., 2007; Justi & Gilbert, 2003; Krell & Kruger, 2016). For example, it was found that in-service teachers in the US and Germany mostly communicated to their students about physics models (i.e., physical representations) instead of the host of other representations that make up a scientific model and allow for the use of models as predictive tools (Krell & Kruger, 2016). If teachers of science have conceptual difficulties with this subject it is reasonable to suspect that they would rarely use modelling activities in the classroom with their students as shown in Schwarz et al. (2009).

Perhaps this issue will resolve itself over time as pre-service teachers who learn about modelling during their educational training join the ranks of their in-service peers. However, this may not be the case. For example, Justi and Gilbert's (2003) found that pre-service teachers in Brazil lacked a true understanding of the nature of science models and Gunes et al. (2004) found that Turkish teachers did not understand the process of scientific modelling. Pre-service teachers' abilities may have improved since then as Harman (2012) found that science pre-service teachers had a grasp of what models were in general but lacked more in-depth knowledge such as the ability to select examples of scientific models and did not seem to understand that representations often used in science such as graphs could be part of a model. More current research has continued to demonstrate that pre-service teachers may be lacking modelling knowledge and thus may not be able to enhance their future students' use of modelling (Göhner et al., 2022; Göhner & Krell, 2020; Yenilmez Turkoglu & Oztekin, 2016).

Additional research into pre-service and in-service teachers' perceptions of scientific modelling and its use in schools, is needed to be able to educate science teacher performance more effectively. This paper reports on a study that investigated how teachers in two countries, the US and Turkey, perceived models, and modelling. Considering, the past research in models and modelling in science (e.g., Gunes et al., 2004; Harmen, 2012; Krell & Kruger, 2016) we hypothesis that the results might be discouraging in terms of both the US and Turkish teachers' perceptions of science models and scientific modelling. However, the findings can inform science teacher educators and educational programs so that they can more effectively prepare teachers for 21st century classrooms. By knowing how these two groups of teachers perceive models and modelling in two countries whose students score in PISA at two different levels can help science teacher educators more effectively address their training needs.

SCIENTIFIC MODELS

The word model as well as scientific model has many different meanings. In this paper we believe that scientific models can either be mental or conceptual in nature (Quinn et al., 2012). Mental models constructed by students are implicit and invisible to researchers, but conceptual models are visible representations of those mental models. These explicit representations can include diagrams, graphs, written descriptions, analogies, mathematical equations, and physical models (**Figure 1**).

Model representations could consist of a 3-D physical model of DNA, a graph of a car moving at constant velocity or the mathematical representations of the ideal gas las. These explicit representations of the conceptual model produced by students allow teachers and researchers to gain insight into the student's mental model.

Models and these associated representations can be used to make predictions about natural systems as well as communicate ideas about science (Giere, 2004; Svoboda & Passmore, 2011). Expert problem solvers have been known for a while for switching fluidly between these representations (Chi et al., 1981; Harrison & Treagust, 2000). Studies have shown that the focus on even one representation such as graphical understanding can influence conceptual development (Roslina et al., 2020). Thus, multiple representations can assist students in making connections between science concepts as well as supporting a deeper understanding of those concepts (Ainsworth et al., 2011; van Someren et al., 1998). The use of models and their multiple representations during school science classes helps to produce improvements in the

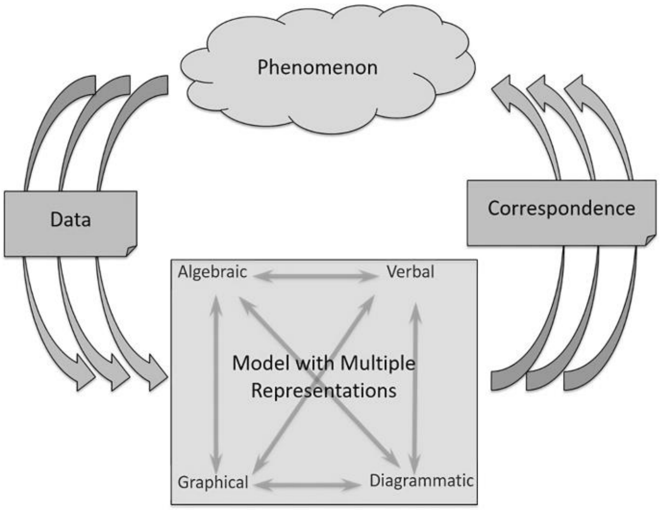

Figure 2. Modelling cycle (Malone et al, 2019)

conceptual learning environment making it more interactive (Dori & Belcher, 2005; Gilbert & Treagust, 2009; Tsui & Treagust, 2003; van Someren et al., 1998; Won et al., 2014). Thus, it can be concluded that science classes that make use of scientific models with multiple representations can be powerful for student learning in science.

Given the research into the importance of scientific models on student learning it would seem important that both pre-service and in-service teachers of science should be exposing their students to their use and development during their courses. However, research has shown that educators may not only be not using the multiple representations but also may be confused in their own understanding of scientific models. Research has shown that in-service teachers utilize only one specific representation of a model (i.e., physical representation) with students in Germany (Krell & Kruger, 2016). Thus, in terms of multiple representations, students in these two countries routinely only experience one representation of an otherwise robust science model. This might not be surprising when one considers that 'model' in education is a noun and one could assume it is a physical object. In addition, the understanding of what a scientific model comprises seems to also be compromised (Güneş et al., 2004). One must question why teachers teach the same way and seem uninformed about better instructional strategies. However, similar issues have been found in all three of these countries in terms of in-service teachers. Thus, we might anticipate that the problem is more widespread.

SCIENTIFIC MODELLING

Just as the model can have multiple meanings so too can modelling or scientific modelling. In this paper the act of scientific modeling specifically refers to students developing models and their associated multiple representations using empirical data, refining them, and using them to make predictions (Quinn et al., 2012). Scientific modelling continues when the model and its representations are tested by determining if they are predictive in different contexts from which the model was initially developed. Based on the findings from these experiments' revisions are made to the model and its multiple representations that allows the model to become more predictive in the same context as well as other contexts. This cycle of testing is known as the modelling cycle (**Figure 2**).

The development and use of the model representations might be what ultimately contributes to the student conceptual gains and their improved problem-solving expertise (de Jong et al., 1998; Tsui & Treagust, 2003, 2007) as it allows students alternative pathways for problem solutions. For example, if a student finds that the use of an algebraic solution does not produce an answer that makes sense, they can check their work by using a graphical approach. Thus, given the benefits of having students undertake scientific modelling exercises it is important that teachers understand not only what scientific modelling is but how to incorporate it into their classes.

METHODOLOGY

Aim of the Study and Research Questions

This study aimed to compare the perceptions about scientific models and modelling held by Turkish and United States pre-service and in-service teachers to determine distinctions between first and second-world countries. Ultimately, we aim to determine issues that may be faced by countries in promoting the use of authentic practices such as scientific modelling in schools.

Specifically, the following question guided this study: *What are pre-service and in-service teachers' perceptions of models and modelling in Turkey and the United States?*

Research Design

To answer the research, question a qualitative study was designed using semi-structured interviews. The first two questions (**Table 1**) in the interview were used for all participants and aimed to uncover their current understanding of models and modelling. The third question was modified to fit the interviewee's context.

Participants

A total of 47 in-service and 41 pre-service teachers in their last year of university training were interviewed. The in-service teachers in both countries were mostly from urban public school settings. The demographics of the in-service teachers can be seen in **Table 2** and those of the pre-service teachers in **Table 3**. The two populations were compared across a number of demographic information, including their attendance at science modelling workshops. Given that a greater percentage of the US in-service teachers had taught longer, held graduate degrees, and attended modelling workshops they could be said to have been expected to perform better in terms of the interview questions.

The pre-service teachers from the United States were enrolled in a large well-established university in the middle of the country. The Turkish pre-service teachers were enrolled in a recently established medium sized university in the eastern part of Turkey. **Table 3** shows the demographic information for the pre-service teachers.

Table 1. Interview questions

Participant group	Common questions	Group specific questions
Pre-service teachers	When we say the word model what does that mean to you?	How do you plan to use models and modelling with your students?
In-service teachers	What does modelling in science mean to you?	How do you use models and modelling with your students?

Table 2. In-service teacher demographics

Country	n	Teaching experience (years)	Grade level	Female (%)	Male (%)	Graduate degrees (%)	Modelling workshop attendance (%)
Turkey	16	8.68	4-8	69	31	31	6.25
The US	31	12.6	K-9	77	23	84	9.6

Table 3. Pre-service teacher demographics

Country	n	Percentage of females	Percentage of males
Turkey	33	66.6	33.4
The US	8	87.5	12.5

Table 4. Model codes & definitions–Examples

Code	Definition
Physical model	A physical representation (such as, DNA structure, cell, & solar system)
Mathematical model	Equation or algebraic representation (such as the equation for determining velocity)
Process of instruction	Step by step showing students how to do something such as an experiment
Scientific model	A representation of a phenomena consisting of multiple representations that together explain unseen/intangible concepts

Table 5. Modelling codes & definitions–Examples

Code	Definition
Physical modelling	Using a physical representation such as a cell model but not necessarily to make predictions
Modelling to solve problems	Solving mathematical problems in science
Modelling as a process	Showing students a process like how materials cross a cell membrane
Scientific modelling	Modelling like scientists, creating own experiments, analyzing data with the purpose to create a model with multiple representations (i.e., graphical, verbal, diagrammatic, mathematical, etc.).

DATA ANALYSIS

The interviews were audio-recorded and transcribed verbatim. The transcripts were initially coded by one researcher using grounded theory (Glaser & Strauss, 1967). Based on the themes that emerged a code book was created. This code book was then used to train a second researcher who then coded several interviews. At this time additional themes emerged, and code definitions were refined and expanded.

Analysis of Teacher Perceptions of Scientific Models

A total of 15 sub codes for describing what teachers considered a scientific model were determined along with definitions based on student explanations (see **Table 4** for example codes).

The interview questions were targeted at revealing both group's understandings about scientific models and how they are and can be used in their classrooms. The codes that emerged from the data about scientific models included comments about what this paper would term the model representations. For example, teachers would discuss the physical representations of a particular model such as DNA replication as the 'physical model' - not clearly recognizing that scientific models consist of multiple representations such as physical, pictorial, and mathematical.

An example of teacher statements that led to a coding of a physical model were:

> Turkey (translated): "It is the material that is made into a material that we can perceive with five senses, in order to examine things that are normally much more difficult to examine."

> The US: "I have to a small extent, … I think models … models that I have built and shown to my students do not lend nearly as much information to my students as having them build them themselves, but we do models of things like solar systems."

These two responses seem to point to the idea that teachers are 'seeing' models at nouns and actual objects that are constructed.

A participant who seemed to have a more scientific understanding of a scientific model was a pre-service teacher who said:

> "Models are kind of a broad range of terminology that have to do with how you can actively process things that are not the most tangible. Typically, things that are intangible concepts. You build models to kind of rationalize, to prove what you cannot see."

This statement earned a designation as a scientific model since the pre-service teacher was discussing that you can use the model to predict outcomes even though s/he did not specifically mention multiple representations.

Analysis of Teachers Perceptions of Scientific Modelling

A total of 11 codes for scientific modelling were determined (see **Table 5** for example codes).

These codes emerged from the interview data. The scientific modelling code was a predetermined code based upon how scientific modelling is defined in the research community. In many cases the teacher's thoughts about modelling were very similar to those made when discussing models as can be seen by the examples below. It seems that teachers had difficulty distinguishing the difference between the two terms–one referring to conceptual objects (i.e., models) and one referring to a process used to construct and utilize the conceptual objects (i.e., modelling). An example of teachers using the term physical modelling are:

Turkish (translated): "Modelling in science, for example, cell modelling comes to my mind. We do not see the cell directly by eyes, but there are the model-styles [we use in class] … to [teach] to students better."

The US: "like I said, there's the constructing cells, and their parts could be using a [inaudible] cells. Could be constructing DNA models and understanding how the DNA works, and body parts, seeing how those … fit in your body and what their functions are."

The comments by these teachers were basically identical for the two different questions. As seen in the US teacher's comment of 'like I said' referring to the previous question about models one can understand that most of the teachers felt the two questions were identical and tended to get frustrated with the questions. It is almost as if they are not seeing that a model is a noun and modelling is a verb. The verb modelling would imply making the physical model but does not seem to imply using that model to make predictions of system outcomes.

Examples of scientific modelling quotes from an in-service and a pre-service teacher are:

An in-service teacher said, "It means that the student or- for me, it means that they're, uh, creating models and creating their- using their ideas to create their understanding of biology."

A pre-service teacher said, "I was actively building models, and I could refer back to those models in order to help me actively process through real world problems."

These quotes earned a designation of scientific modelling even though they did not mention multiple representations because they focused on student's use of the models to make predictions and to compare their findings to those predictions.

After the codebook was finalized, an interrater check was conducted using 10% of the transcripts. The strength of agreement was considered good for comparative study with a Cohen's Kappa score of 0.83.

RESULTS AND FINDINGS

The percentages of teachers in each country, both in-service and pre-service, mentioning each code were calculated and graphed for comparison. During this process it was seen that many teachers, both pre and in-service, felt that the questions about models and modelling were the same. This was discovered when comparing their answers to each question. The teachers would describe using a physical model when asked to describe models and scientific modelling. This implies that teachers do not have a good grasp on the differences between the two. They do not seem to realize that a model is simply a conceptual representation while modelling is using the conceptual representations to produce outcome predictions. Perhaps they did not understand that there was a difference between the two terms or were not expecting the use of modelling as an active verb. In this analysis even if a teacher was not using his/her definition for scientific modelling in an active sense we still coded it as modelling. The percentage of teachers being coded for diverse types of descriptions does not add up to 100% since many teachers mentioned several different alternatives for each question. In these cases, their answers were associated with multiple codes.

In-Service Teachers

The majority of in-service teachers in both countries described models in science mostly in terms of physical models or representations (**Figure 3**). The second most popular way to describe models was to

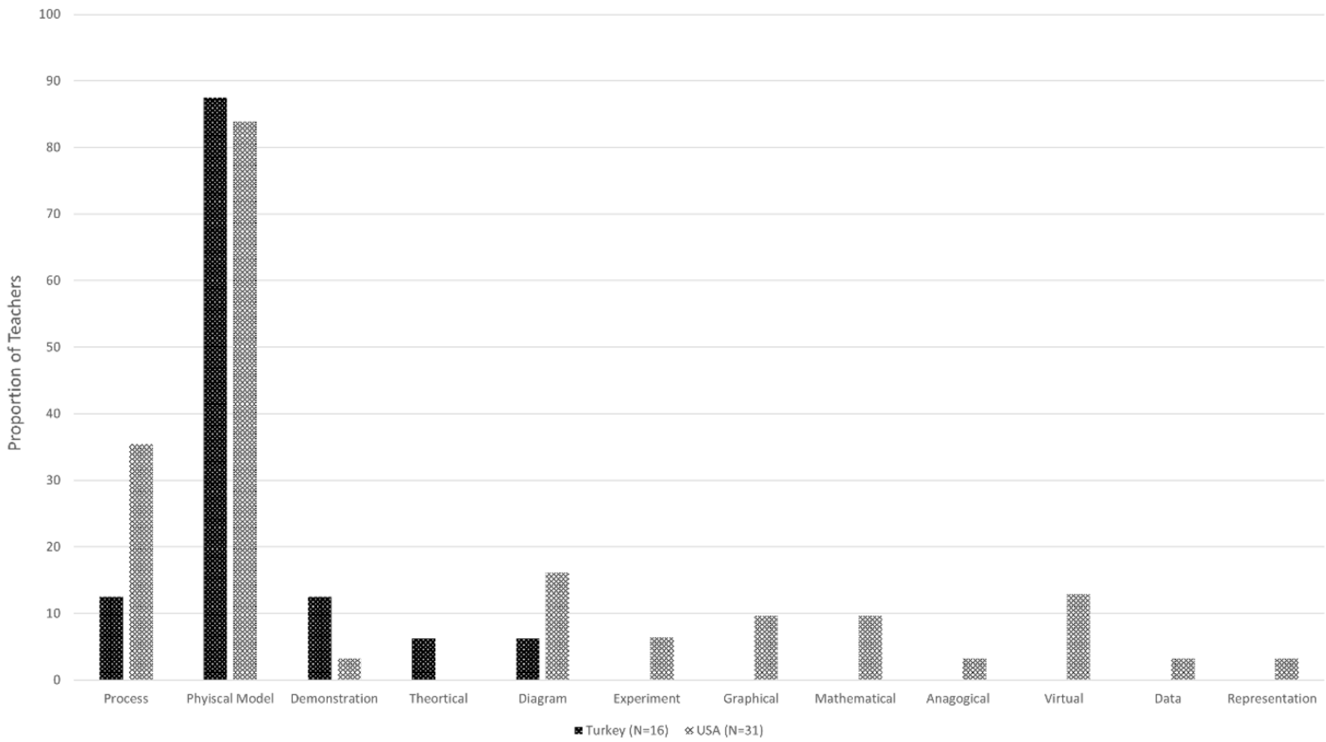

Figure 3. In-service teachers: What is a scientific model? (N represents the number of participants in each cohort) (Source: Authors' own elaboration)

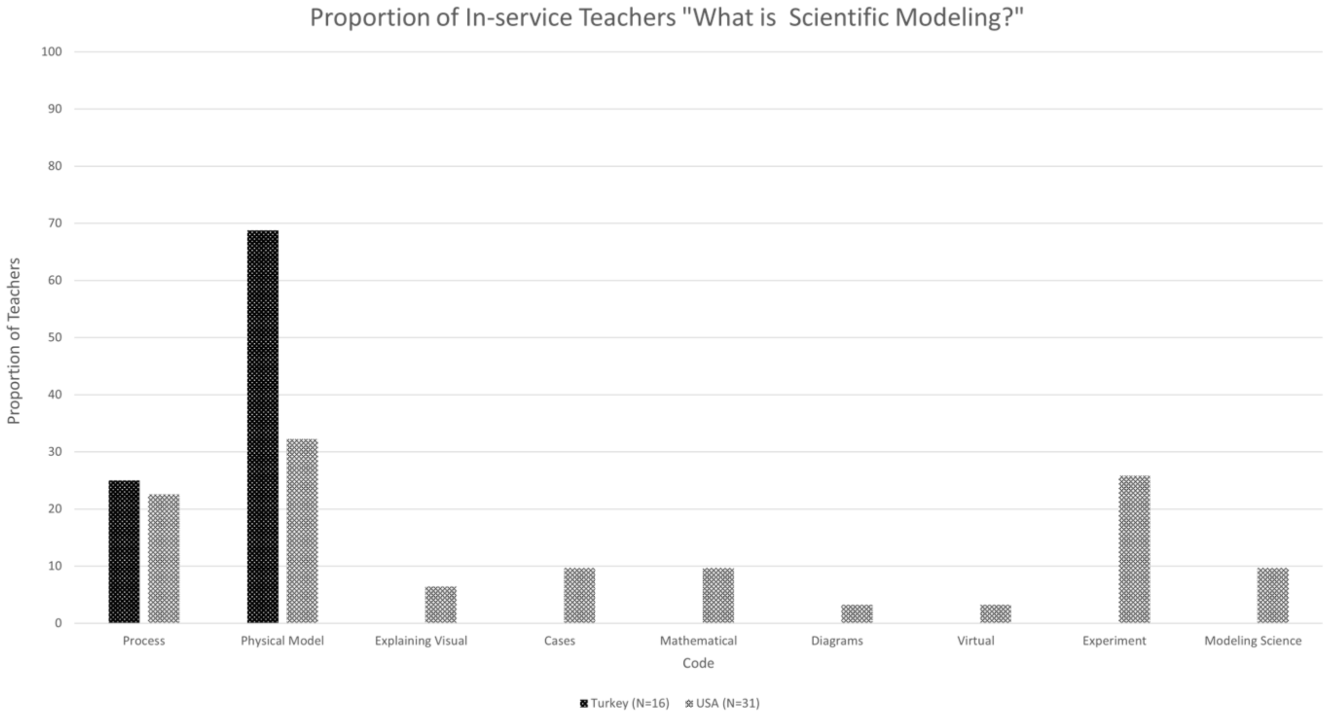

Figure 4. In-service teachers: What is scientific modelling? (N represents the number of participants in each cohort) (Source: Authors' own elaboration)

describe them as a process that would be modeled for students. While this was the second most popular way it was much more predominate among the US respondents than the Turkish respondents, 36% vs. 13%, respectively. In addition, no in-service teacher from either group described using a fully scientific model.

The main difference between the two cohorts was that the Turkish teachers described a model by using only three other alternatives, specifically, model as a demonstration, as a diagram and as a theory while the US teachers utilized up to nine alternatives (**Figure 3**). The proportion of participants in each group for all figures may not add up to zero since participant statements could have been assigned multiple codes.

When asked about modelling in science, in-service teachers in both countries described modelling in terms of using a physical model (**Figure 4**). Thus, there remains the conflating of models as noun with modelling as a verb. The second most popular description for modelling differed between the two countries. Turkish in-service teachers preferred discussing scientific modelling as modelling a process used in class. For example, this included modelling how to do a specific lab technique. In the case of the US teachers their second most popular description of scientific modelling was performing an experiment step-by-step to collect data to confirm a scientist's model.

None of the Turkish teachers mentioned this as an option. Only three teachers, all the US, were coded as describing in full a description of using scientific modelling in their classes. Two of the three had taken a modelling-based workshop in the past. Thus, two teachers, one Turkish and one US, who had taken a modelling-based workshop did not describe the true use of scientific modelling in their classrooms.

Pre-Service Teachers

The pre-service teachers also showed interesting differences across countries. The majority of pre-service US teachers described a model as a process that is modeled for their classes such as showing how to complete a problem. The US pre-service teachers' second most popular description was to suggest a scientific model could be a diagram or an experiment while the Turkish pre-service teachers focused on a model as a physical entity. Only one US pre-service teacher described a model as a scientific model (**Figure 5**).

When asked about modelling the US and Turkish pre-service teachers were not similar (**Figure 6**). The Turkish pre-service teachers described modelling as the use of a physical model while the US pre-service teachers described it as modelling a process for their students. Thus, the pre-service teachers were holding the conception that a model is a noun while modelling is a verb. In both cohorts, only a single pre-service teacher described modelling congruent with the scientifically accepted definition.

Comparison Between In- and Pre-Service Teachers

When comparing pre- and in-service teachers regarding perceptions of a scientific model, both groups focused on a model as being either a physical model or a process model. A greater proportion of pre-service teachers described examples that could be coded as truly the use of scientific models or scientific modelling. However, the biggest difference was that the US pre-service teachers did not describe physical model(ing) but focused on demonstrating a process when asked about scientific modelling. It is possible that this is a consequence of pre-service educational training that focuses on modelling pedagogical practices during in-service training (Harbour et al., 2015; Loughran & Berry, 2005; McCullagh et al., 2012); whereas most science courses rarely make use of scientific modelling (Schwarz & Gwekwerere, 2007). But all the in-service teachers and the Turkish pre-service teachers highlighted physical modelling as well as modelling a process when asked similar interview questions.

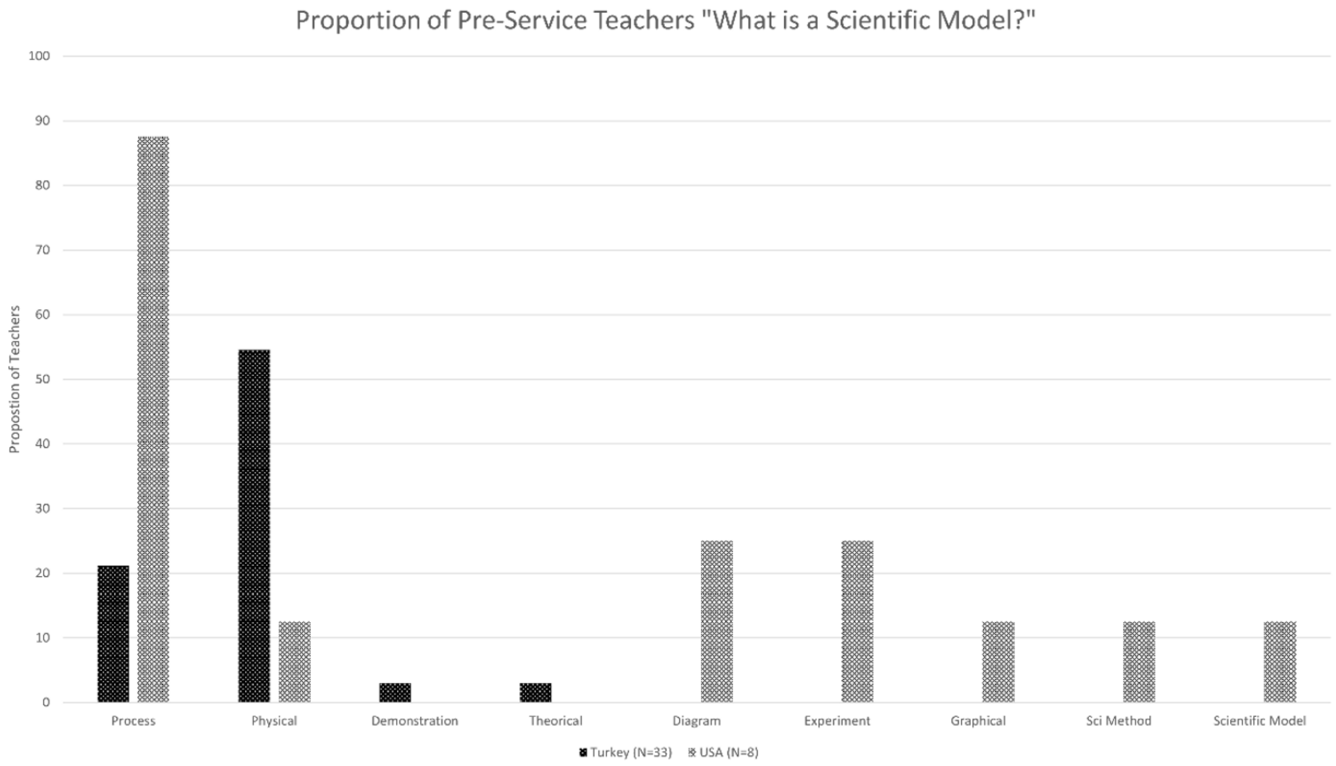

Figure 5. Pre-service teachers: What is a scientific model? (N represents the number of participants in each cohort) (Source: Authors' own elaboration)

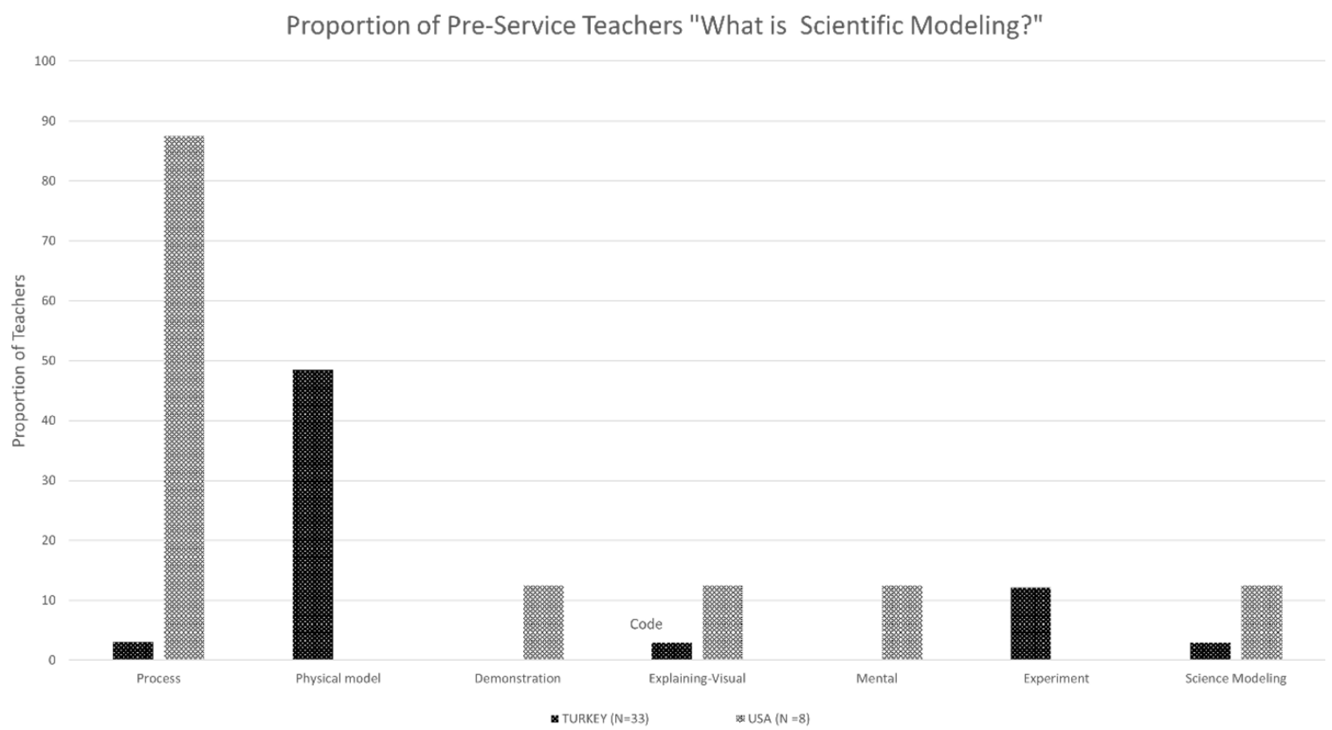

Figure 6. Pre-service teachers: What is scientific modelling? (N represents the number of participants in each cohort) (Source: Authors' own elaboration)

DISCUSSION

The results demonstrate that pre-service and in-service teachers in this study do not have a clear understanding using science models and scientific modelling in their science classrooms even through this has been shown to be an issue over 20 years ago (Gilbert, 2004; Justi & Gilbert, 2003). Both pre- and in-service teachers do not seem to have a conception that a model has multiple representations. This is disturbing especially if one considers that pre-service teachers should be the most up-to-date on new pedagogical methods, such as scientific models and modelling. The data suggest that while many teachers may use one or more multiple representations in their classes, they seem to consider them as separate models. In addition, it is unclear whether teachers use them in a predictive sense during modelling activities. Thus, the idea that a scientific model consists of multiple representations does not seem to be an understanding shared by in- or pre-service teachers, whether they are located in Turkey or the US. Research in Turkey implies that the problem with understanding modelling may also extend to the area of mathematical education for both pre- and in-service teachers (Isik & Mercan, 2015). These misconceptions of scientific models and scientific modelling that are shared by Turkish and the US teachers seems to point to a failure ultimately in both countries in terms of science education at the university level. However, is this associated with just these two countries. Research shows that it does not seem to be case given that pre- and in-service teachers' in other countries have difficulty with alternative approaches such as modeling (e.g., Krell & Kruger, 2016, Saleh & Jing, 2020). Indeed, recent research has shown that pre-service teachers feel that the emphasis of pre-service education is on knowledge development and not authentic practices (Bahtaji, 2023). Changes in science education methods courses as well as general science courses at the university level in both countries are not supporting teachers in an understanding of the authentic practice of scientific modelling. Changes need to be made at the university level that could support long term shifts in pre and ultimately in-service teachers understanding of scientific models and modelling which in turn would help support increases in student performance on international tests in both countries. These changes should include educating pre-service science teachers in science methods classes about the role of science models and scientific modelling in the education of our pre-collegiate students as well as allowing them to practice teaching using science models and modelling. However, recent studies have shown that just having meta-modeling knowledge will not allow for an increase in the use of models and modeling (Göhner et al., 2022). Therefore, in addition to meta-modeling knowledge, general college science classes for both science and non-science majors should be redesigned to allow students to experience developing scientific models as well as using them doing scientific modelling activities. Only by experiencing these methods directly in both their education courses as well as their general science classes will we find a shift in pre-service teachers understanding and appreciation for the use of scientific models and modelling in the classroom happen. Finally, in-service teachers need to have support via in-service workshops and job embedded professional development to shift their practice towards the use of scientific modelling in their classes. Only intense training can shift their perceptions of scientific models and modelling.

CONCLUSION

This study has shown that issues about science teachers (both pre- and in-service) understanding of science models and modelling continues to be a major issue in multiple countries. The countries studied in this paper both focus on authentic science practices and modeling in science. Thus, it is disturbing that secondary science students in this country will not receive the benefits that could have been afforded them by teachers with a solid grasp of the use of science models and modelling.

Future Directions

Ultimately, more counties should be included in the study to determine how common these issues are globally. Ultimately, the generation of a web administered survey based upon teachers' responses could allow a greater number of countries to be included in the study. Thus, policy makers and administrators in both countries must take into consideration supporting intense changes to in-service training as well as pre-service teacher education when issuing policy changes, especially in the case of authentic science education. This study shows that if countries make changes in standards to include reformed science education practices such as scientific modelling, they must commit to retraining educators in order to accomplish changes in student learning along with increases in international testing such as PISA.

Limitations

This study does have several limitations. First and foremost is the small number of the US pre-service teachers who were interviewed. In addition, the participants were from only two countries and then only specific areas in each of these countries.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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