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DESIGN OF A SOCIOSCIENTIFIC ISSUE UNIT WITH THE USE OF MODELING: THE CASE OF BEES

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A major aim of science education reform documents (Achieve, 2013) is for K-12 students to engage in scientific practices to facilitate a better understanding of the processes and the aspects of doing science (Bybee, 2014). In this design case we present the design of a teaching unit on a socioscientific issue (SSI) that can potentially engage learners in modeling and argumentation. The unit focuses on the controversy about the declining population of honeybees. The "Should we care about the bees?" unit engages the participants in the practice of modeling for explaining and arguing about the causes, consequences, and possible solutions related to the problem of the bees. Our unit aims to illustrate how to address the intersections between science and society and to promote scientific practices in science learning and teaching. Two university science educators from different countries worked together to design and re-design the teaching unit. Initially the unit was designed in order to promote the exploration of the socio-scientific issue through argumentation, but after an initial implementation we decided to focus on modeling the issue as well. The final design product is a seven-week unit. In this paper we discuss design challenges and decisions of using an SSI based unit that promotes learning and teaching SSIs in the context of scientific practices.

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INTRODUCTION

It is suggested that argumentation in socioscientific issues makes scientific learning meaningful because these issues provide a context that connects science to everyday life issues, where citizens are expected to take an active role (Puig & Jiménez-Aleixandre, 2011). In our work, SSIs are defined as those issues on which our society or science are clearly divided, and significant groups advocate conflicting explanations or solutions (Evagorou et al., 2014). These solutions can be informed by scientific principles, theories, and data, but they cannot be determined by scientific considerations only. Decision-making or other courses of action associated with these issues are influenced by a variety of social factors, including politics, economics, ethics (Sadler, 2011) and how individuals identify with the issue.

Teaching SSIs, through engaging learners in scientific practices, goes beyond implementing a new curriculum. It requires a pedagogical shift from a traditional, content-based, and value-free instruction approach to a sociocultural approach that views science as a community practice, and the students as active participants in decision-making processes (Tal & Kedmi, 2006). Implementing SSIs is challenging for teachers as it puts a demand on them to draw on knowledge stemming from other domains, and also to appreciate and to present to the students the societal aspects of science (Simmoneaux & Simmoneaux, 2008). For instance, teachers find it difficult to guide the learning and to assess the performance of students in terms of their arguments (Evagorou, 2011). Therefore, teacher educators need to explore the pedagogical challenges of teaching SSIs and

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to improve the knowledge about the pedagogical training that teachers need for the effective implementation of SSIs units.

In an effort to prepare an elementary pre-service teacher to teach socioscientific issues (SSIs) we designed a teaching unit to engage them in SSI argumentation and modeling. This design case aims to describe the development of this teaching unit, with an emphasis on the challenges and decisions taking place during this process.

CONTEXT

Both authors live and work in Europe and are active in research and teacher professional development in their countries. In the European context, the current emphasis in innovation in science education has been placed on the use of inquiry-based science education (IBSE) and in supporting the teachers adopting this approach in the classroom. Currently, our countries have adopted the PISA 2015 framework (OECD, 2013; 2015), which recognizes three scientific competencies: 1) Evaluate and design scientific inquiry (*inquiry*), 2) interpret data and evidence scientifically (*argumentation*), and 3) explain phenomena scientifically (*modeling*). These scientific competencies correspond to the three broad practices of the NRC framework (Jiménez Aleixandre & Crujeiras, 2017).

Despite the reforms, and the emphasis on the practices or skills, science in most schools is frequently taught through lectures, which generally helps learners gain an understanding of a subject of use on standardized tests but often without deeper understanding (Bransford et al., 2000). Furthermore, the 2015 European Report "Science Education for Responsible Citizenship" calls for close collaboration between all actors to develop scientific citizenship and address emerging societal challenges. This move towards "Responsible Research and Innovation (RRI)" responds to a new challenge:

> *"As the world becomes more interconnected and competitive and know-how expands, new opportunities along with more complex societal challenges arise. Overcoming these challenges will require all citizens to have a better understanding of science and technology if they are to participate actively and responsibly in science-informed decision-making and knowledge-based innovation (…)" (European Union, 2015, p.7).*

With RRI being a new concept in Europe, a lot of researchers link RRI with SSI and responsible citizenship (Owen, Macnaghten & Stilgoe, 2012). The main ideas of RRI and SSI, both emphasized in the new European curriculum, can help us move towards science education learning science in connection with everyday life issues through scientific practices. However, as researchers and teachers working in the area of teacher professional development, one of the challenges we face is to equip teachers with resources and strategies to develop learning environments that promote this approach.

Therefore, in our countries we consider that there is a gap between theory and practice regarding the implementation of SSI and scientific practices, since these ideas are included in the reform documents, but the teachers, especially elementary school teachers are not prepared to apply them in their classrooms for two main reasons: (a) they do not have the necessary skills or training to be able to do so, and (b) there are limited teaching resources in our languages to support the teachers in implementing SSI and scientific practices in action.

DESIGN MOTIVATION

As researchers and teacher trainers of elementary teachers, we both face the gap between research and practice. We read studies about how students engage in SSI and various scientific practices, and then we struggle in reality with teachers in our countries who do not have the support and resources to do so. Furthermore, we both work with elementary pre-service teachers who often lack the motivation and skills to teach science, and have negative attitudes towards science because of their experience as learners. Taking into account all the connections between our research and our current concerns, we decided to collaborate and prepare a teaching unit to support our pre-service teachers to teach an SSI through the scientific practice of argumentation.

At the time that we started the collaboration, Maria Evagorou was working on a European project centered on preparing science teachers to teach everyday life issues, designing a framework to engage elementary and secondary primary pre-service teachers (PSTs) in critical discussions of everyday science through SSIs. Blanca Puig was working on a Spanish project to explore scientific practices in the science classroom, in which she was involved in the design of SSIs activities and units for the promotion of scientific practices and critical thinking in learning science. As science educators we were both interested in deepening our understanding of how to prepare teachers to implement SSIs through scientific practices in an effective and significant manner.

INITIAL DESIGN PROCESS

Even though over several years, we discussed our concerns and ideas on the aforementioned topics, we were given the opportunity to work together in May 2015 when Blanca Puig visited Maria Evagorou under an ESERA (European Science Education Research Association) research grant. This grant aims to bring researchers from across Europe together to collaborate. Even though the initial concerns and ideas were discussed over several years, the teaching unit, as presented here started being developed during Author A's visit when we had the opportunity to have several work meetings and develop our ideas idea.

Design decision 1: Bees as the SSI in our unit

During our first meeting in Cyprus, B. Puig presented an inquiry-based activity that she had implemented with one of her classes about the bees. In order to have a broad view of the problem of bees, B. Puig consulted an international expert on honeybees and botanists. He has more than 30 years of experience working with beekeepers, and he organizes dissemination activities about bees for schools. He leads an educational centre of honeybees in Galicia (Spain), open for visitors that many kindergarten and primary schools visit to see the bees in their hives and the process of honey's production.

The honeybee expert provided information about the situation of honeybees all over the world. Based on data collected in EU countries, the situation of bees is similar in many countries. In particular, Cyprus and Spain face similar problems that affect the population of honeybees, as for example, the excessive use of pesticides in crops.

In this activity, which aimed to engage pre-service teachers in inquiry, the PSTs were provided with four different types of honey and description cards and had to identify the type of honey-based on the various characteristics (density, smell, color, taste). Then the students were given pollen and were asked to match the pollen to the honey and explain their reasoning. Author A also wanted to link this unit to the idea of the declining population of the bees and how this might affect crops in her hometown.

After discussing what B. Puig did with her students we agreed that the SSI topic was of importance, and we could both find ways to link it to the local curricula that could potentially be used by the PSTs in their future practice since, in our countries, the primary education curriculum deals with living organisms. We decided to focus on the causes of the bee declining, the consequences, and then, in the possible solutions. The decision was to present the following problem: the population of the bees around the world is declining, and in the long-term this can affect the crops, biodiversity, and the production of food. It is a global and complex problem that affects our countries very much, so we decided to address the controversy together through this case design. The modeling of bees requires understanding their role in ecosystems, the causes (or threats), and the consequences of the depletion of bees. All of these issues are very much connected and conform to a "controversial chain."

Design decision 2: Emphasis on argumentation through an SSI

Both authors are researching in the areas of argumentation and SSI during the last years; therefore, from the beginning of our collaboration we knew that we wanted to continue within these areas. We were interested in how pre-service students develop their arguments and justify their decisions within this area of bees.

Design Decision 3: The structure of the unit and links to local curriculum

After deciding on the SSI topic and argumentation, we started thinking about the structure of the activities.

Taking into consideration similarities and our science curricula for primary students, we decided to name the unit, "Should we care about bees?" The Spanish curriculum for primary education (MEC, 2014, particularly natural sciences, points to the importance of students' development of knowledge and attitudes of respect and appreciation for plants and animals. The identification of living beings and the comprehension of its roles in the environment is addressed in the curriculum, as well as the human impacts in the environment. Insects as honeybees offer significant learning opportunities regarding diverse biology topics that are interconnected and appear in the curriculum (e.g. ecosystems, biodiversity, pollination). Besides, primary education curriculum in Spain is oriented towards students' development of key competences, being scientific competences, as inquiry and argumentation, central in scientific disciplines. The Cypriot curricula (MoEC, 2010) places an emphasis on the development of scientific practices, especially argumentation, and on the connection of science to issues that are relevant to the local community in order to make science relevant to students' everyday lives. The primary education curriculum focuses on four areas: living beings, human body, physics concepts, and environmental issues. Bees and their role in the environment are addressed in the primary education curricula.

In Figure 1 we present the design process, conducted during 2014-2015

Table 1 presents the activities of Version 1, and the scientific practices promoted. As Table 1 shows, all activities, except the introduction, were linked to argumentation.

INITIAL IMPLEMENTATION AND DESIGN DECISIONS

The first version was implemented by B. Puig in Spain in June 2014 with a group of 22 PSTs enrolled in their fourth-year of a degree in the subject Environmental Education. The results of the implementation of the first version were discussed by both researchers, paying attention to students' difficulties in understanding the SSI and in presenting arguments based

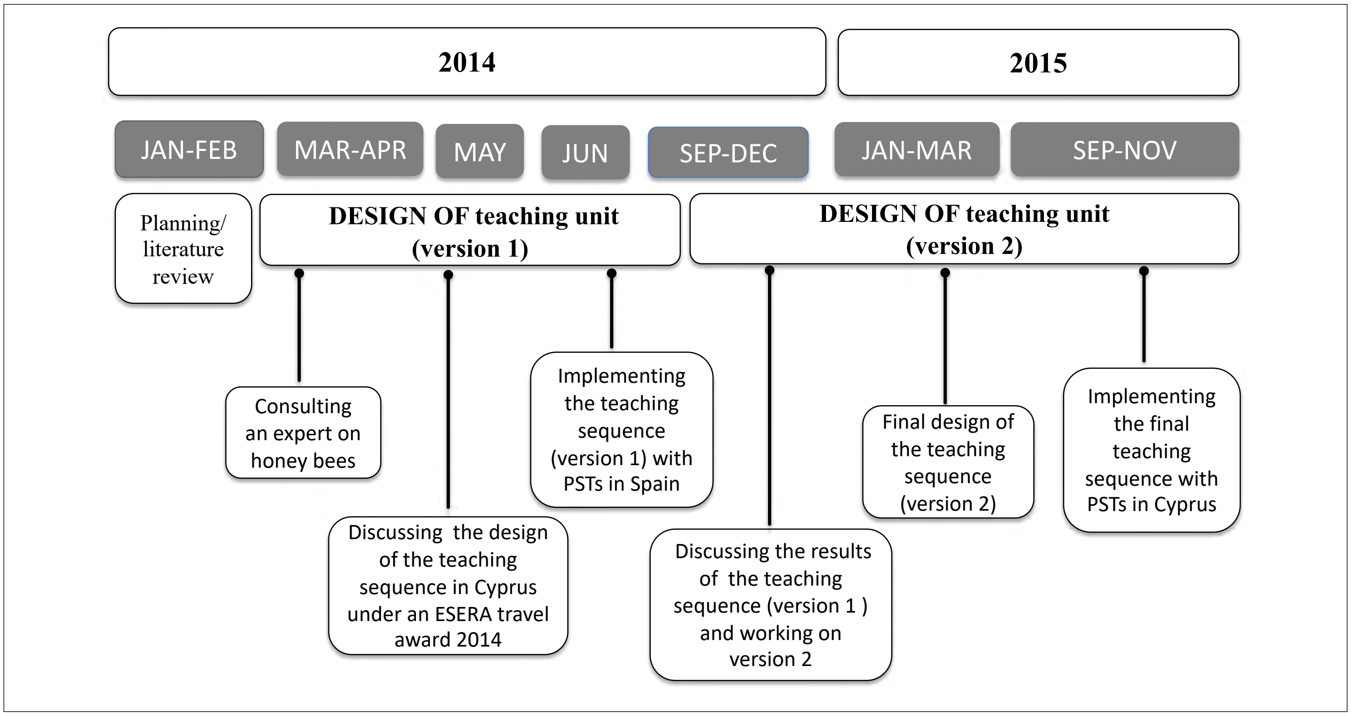

FIGURE 1. Summary of the process of design of the teaching sequence.

ACTIVITIES	SCIENTIFIC PRACTICES/ CONTEXT
1. What do you know about bees?	Introduction activity
2. Honey testers	Argumentation & use of evidence in the identification of different honeys
3. Which one has produced the honey?	Use of evidence to distinguish bees, wasps and bumblebees
4. What can we learn by observing the pollen?	Argumentation & use of evidence to relate different samples of pollen with ecosystems
5. Is it possible to live without bees?	Argumentation & use of evidence in the evaluation of opposite claims related to the declining population of bees.
6. What is your view about the problem of bees?	Argumentation & use of evidence to support your own view about the problem of bees filming a video.

TABLE 1. First version of the teaching sequence.

on the evidence provided. Based on these findings, PSTs' ideas about the role of bees in the ecosystem were limited. They did not have a clear idea about the importance of bees for pollination and about how plants benefit from bees' pollination. They had difficulties to use the evidence provided in Task Five about the role of bees and how plants and bees help one another to evaluate two opposite claims about the consequences of living without bees.

Design decision 4: Include modeling as part of the unit

After discussing B. Puig's implementation and her students' difficulties, we thought about including modeling as a way to help students better understand bees as elements of the ecosystem. Furthermore, M. Evagorou, during the last years, became interested in modeling as a scientific practice, and especially in how modeling might support younger students (K-6) when arguing about an SSI. The idea of bringing together these two practices as part of this design came from another project that M. Evagorou had with elementary school students in which they engaged in modeling and used their models to present and support their arguments about their decisions (Nicolaou, Evagorou & Lympouridou, 2015). Based on an initial discussion we agreed that this is an area of interest, and we wanted to explore whether modeling could support pre-service teachers. In line with Mendonça and Justi (2014), we view modeling and argumentation as practices that are very much interconnected in a way that they mutually promote each other. Engaging students in modeling and argumentation for learning about the controversy on the declining population of bees may help them to understand the complex and systemic nature of the problem, and to use evidence to argue about its causes and consequences. At the point we came across the work of Friedrichsen et al. (2016) in which they designed an

Week	Activity	Scientific Practice
1	What do we know about bees? Honey tasters and pollen identification	Inquiry & argumentation
2	Building a model of a hive	Modeling
3 & 4	Redesigning and discussing a model of a hive	Modeling & argumentation
5 & 6	Using scenarios (varoa mites, pesticides, destruction of green areas)	Argumentation with the use of the model
7	Reflecting on the process and the practices	

FIGURE 2. Summary of unit 2 "Should we care about bees?"

SSI curriculum using the following structure: presentation of an issue that is compelling for the students, students work with the phenomenon through engaging in scientific practices (namely modeling and explanation in our study), and making use of technology – therefore content and practices develop together, and finally the evaluation of the explanations provided by the students. We decided to follow a similar structure. In our design, participants were presented with the SSI after engaging them in an activity that helps them to identify their own ideas and experiences with bees, as long as with one of the roles they have, the production of honey, and the problem of their disappearance. Hence, this raises questions at personal and social levels as what does the problem of bees means for you? How do you see the problem of bees? What are the issues connected with this problem?

Therefore, the second version of the teaching sequence (Version 2) aimed to engage pre-service teachers in modeling the SSI as a way to help them understand the importance of bees for the ecosystem, and argue about the problem. The design and implementation of the second version of the teaching sequence is discussed in the following section. This is the design that was implemented in Cyprus (see Figure 2).

SHOULD WE CARE ABOUT BEES?

The second version of the teaching sequence aims to engage pre-service teachers in modeling of the bees' community as a means to support them in providing explanations about the importance of bees. The time frame of this sequence, seven weeks, was decided according to the time allocated to the specific courses, and the objectives of the course. The design and implementation of the activities were discussed by the two researchers, taking into account the results of version 1 and research on SSIs through modeling.

The entire teaching sequence, as presented next, was carried out with 20 pre-service teachers, studying to become elementary school teachers in Cyprus. All the participants (18 females and two males) were in their third-year of studies of a four-year Bachelor's degree in Education. This is a similar population to the one B. Puig used in her initial implementation.

The sequence was implemented over a period of seven weeks, as described next:

WEEK ONE: During the first week of the instruction, the PSTs carried out two activities; an introduction task and an inquiry-based activity. The introduction task (see Appendix 1) was developed in order to make PSTs knowledge of bees explicit. It includes 5 open-ended questions about the role of bees, honey's characteristics, and the problem of the diminution of honeybees. Participants were not provided with any information for answering these questions since we were interested in their previous ideas and opinions on the problem.

The inquiry-based activity, "Honey testers" aimed to engage PSTs in exploring the characteristics (smell, test, density, colour) of different types of honey, and then to identify them. Specifically, five bottles with different types of honey were provided to each group of PSTs, and they had to study them in terms of their different characteristics. Then, based on an identification key they had to recognize the type of honey, linking it to the characteristics of the pollen that it came from. The purpose of this activity was to engage the PSTs in the process of understanding where the honey comes from, and what is the role of the bees in this process.

FIGURE 3. Two-dimensional models of group A.

FIGURE 4. Three-dimensional model of group A.

WEEK TWO: During the second week, the PSTs were provided with some information on honeybees, and how their communities are organized. The purpose was to understand how the community of honeybees works inside a hive and how the bees interact with the environment. The PSTs could also use computers in the classroom to collect any other information from the Internet.

The final outcome of this activity was a two-dimensional model of the hive showing the relationships in the hive (queen, drones, workers), and how they interact with the outside environment. Figure 3 shows the model elaborated by one group.

WEEK THREE & FOUR: the PSTs constructed three-dimensional models of beehives and their environments. During the model construction process, each group received feedback from the instructor and other groups as to how effective their model was in presenting the processes that take place both within, and outside the beehive. At the end of week 4 all groups presented and explained their models. Figure 4 shows their three-dimensional models.

WEEK FIVE & SIX: the PSTs were presented to the problem: "The population of the bees worldwide is declining. Should we care, and why?" Initially, they were asked to give their answers as groups, using their knowledge from constructing their models to explain their answers. Then, they were provided with different scenarios that have to do with causes of the declining population of the bees (e.g. varroa mite, people destroying natural habitats, chemical spraying of crops), and they were asked to use their models to explain the problem, to show the changes that are taking place over time in their models, both short-term and long-term.

For each of the scenarios, they had to prepare a short video clip showing the consequences, using their model, and argue about possible solutions.

WEEK 7: During this week, the students reflected on the activities, and discussed why the bees' issue is an SSI. Furthermore, they were asked to choose a topic that they wanted to teach to elementary school students and design a lesson plan. This was their final project.

DESIGN REFLECTIONS FROM THE SECOND IMPLEMENTATION

In order to evaluate the teaching sequence, we collected PST's reflections of the process, their discussions in groups during the lessons and final models. Research findings from the implementation of this teaching sequence are presented in Evagorou and Puig (2017).

Design Reflection 1: Content expertise

As educators, we found the idea of using the bees as an SSI very interesting and also very relevant to the elementary school curriculum that future teachers will apply in their classes. One of the challenges however in implementing the unit is that none of us is an expert in the area, and we had limited knowledge and understanding of the issue of the declining population of bees. Even though B. Puig initially contacted an apiculture expert to help her with the first design of the unit and the information to be included, M. Evagorou found some of the questions the students had challenging. Especially as they were constructing their models and were trying to understand the ecosystem, they had specific questions. M. Evagorou contacted an agronomist during the implementation of the project to help her with questions that the students had.

Design Reflection 2: Making the problem visible improved the learning

The pre-service teachers (PSTs) looked for more information on how the bee community is organized in order to improve their models, and improving their models improved their understanding of the bee community and helped them improve their arguments. Through modeling a socio-environmental problem like the bee's problem in our sequence, students seem to develop a system view on the problem rather than a linear thinking (cause-effect). Therefore, we hypothesize that modeling may help students to visualize the interactions between the different elements involved in an environmental issue, and to reason about them in a more holistic approach.

> *"During the modeling process, we were able to understand the factors that affect the bees and also to see the consequences of the changes to the environment on the bees, and then on the humans. We were also able to think of possible effects on proposed solutions. So our initial group argument was influenced by our understanding of the bee community. And this understanding was improved during the creation of our models since then we had to collect more information to understand and represent the problem." (Christia- female – post reflection).*

Design Reflection 3: PSTs improved on aspects we had not foreseen

One of the main issues that came out from the implementation of the second version of sequence is that by engaging PSTs in an SSI with an emphasis on argumentation and modeling we can help them understand the social aspects of science. More specifically, most of the PSTs of the study did not refer to the social aspects of science before engaging with this unit. On the contrary, they talked about science either as content, as skills, or as a combination of content and skills. After engaging with the teaching unit more than half of the participants offer a view of science that refers to the social aspects of science as well. A representative quote is provided next.

> *"Science is not only about the theories. It is also about scientific practices. By engaging students in the modeling of a socioscientific issue, we allow them to explore the topic and discover on their own the characteristics of science. In this way the students gain autonomy and develop critical thinking. Through science the students can make decisions based on evidence – a skill that will help them as future citizens" (PST 4, post-reflection)*

What is also interesting is that some of the PSTs use the SSI that was used in the teaching sequence to link it with the social aspects of science. Specifically, these pre-service teachers refer to the community of bees as a model that can demonstrate how we should be collaborating as scientists and as societies. Specifically,

> *"Science can help form a person's character and help them have a critical evaluation towards questions by looking into data and evaluating data. By engaging in socioscientific issues in science, we can use our knowledge from science in other topics as well. For example, during the bees lesson we learned how the bees are organized which gave us an example on how society can function, and how important each member of the society is in achieving something collaboratively. Through this example, through science, we can understand what it means to be a responsible member of the society" (PST 6 – post-reflection).*

Design Reflection 4: The language barrier

Working in a design case across countries involves not only working in collaboration, but also integrating different approaches and experiences. We believe that this can enrich the process of designing SSIs activities as well as research on these issues.

In this design case, we worked together in order to design, implement and analyze a sequence of activities related to an issue affecting both countries. The process of designing the unit required taking into consideration our cultural contexts as well as the identification of commonalities and differences on the SSI addressed in both countries. Furthermore, for the design, linguistic issues were also important. The materials were built and designed in different languages therefore they can be implemented in these and other countries. For the significant implementation of the activities, some adaptations were made, such as the type of honey we used (that is the most common in each country), the pollen we used, and the scenarios provided in modeling activities. These adaptations responded to the context since we see as crucial to link a global SSI with a local context.

Despite our design decisions after the first implementation helped us to improve the teaching sequence and the learning experience for our pre-service teachers, as it is shown earlier, some shortcomings were identified in the second version of the sequence. The elaboration of models requires more scaffolding by teachers in terms of making explicit repeatedly the goal of the model during the modelling task.

Otherwise attention may be placed into other aspects that are not relevant for the SSI learning.

Besides, the diverse scenarios provided for arguing about the problem of the bees were not enough if we want students to transfer their models. The scenarios presented helped them to understand each factor that affects the bees' population, although it would be desirable finishing the modeling task asking them for integrating these scenarios in their final arguments. In other words, asking them to argue about the problem of bees considering the diverse scenarios previously modeled.

Furthermore, this second design did not allow us to see to what extent PSTs increased their previous knowledge on the bees, plants, their mutual interactions, and the socio-environmental issue addressed. All these shortcomings could be addressed in further implementations using a 'modeling talk' explicitly and engaging participants in a reflection not only about the practice, as in task 7, but also on the scientific content applied during the modeling process. Asking students to compare and evaluate their own models (the elements and representations used and included) according to the scientific reality, may be beneficial for this purpose.

CONCLUSIONS

For the authors as a design team, this teaching unit represents a successful collaborative design study. Our initial motivation was to collaborate on a research project, but the decision to design our own teaching unit proved to be the most challenging part of our collaboration. Although we thought that designing and implementing the unit would be a straightforward activity, it proved challenging, especially because we had to coordinate between different countries and languages, and we explored an issue for which our own understanding was limited.

Our design decisions after the first implementation helped us to improve the teaching sequence and the learning experience for our pre-service teachers. As we are writing this paper, we are implementing the teaching sequence again with our pre-service teachers with new design decisions that help us adapt to our learners.

Our future work will place an emphasis on whether and how pre-service teachers transfer these practices (argumentation and modeling) in their own teaching. The information that will be collected will lead to new design decisions about the teaching sequence.

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APPENDIX 1. ACTIVITIES OF THE UNIT

ACTIVITY 1. WHAT DO YOU KNOW ABOUT BEES?

1. What do you know about bees? Do you think that they are important? Why?
2. Do you have any experiences with bees? How are your experiences, negative or positive? Explain your answers
3. Could you tell me something about how do they live and what do they eat?
4. Could you describe what is the honey? Where does it come from?
5. What makes the honey taste different to some others?
6. If somebody says to you that bees are decreasing, do you think that this is a problem? Explain why.

ACTIVITY 2. HONEY TESTERS

Part 1: Honey identification

Problem presented: May 6th, as every year, the fare of honey, where the traditional taste of honey from different parts of the country carried out, will be celebrated. Beekeepers from different areas (4 groups of the class) will be participating in this event providing a bottle of honey from their best hive and evaluating the honey of the other participants. This year, in total, five honeys will be tasted and assessed by the beekeepers because there is one bottle of honey that an anonymous person have sent to the organization of the event and the organizers have decided to include it in the tasting event in order to identify it.

The tasting requires:

1. To identify each bottle of honey, from which beekeeper and from which plant every honey comes from?
2. To find out which honey is the anonymous, and what type of honey it is, whether is homemade or not.

Questions

Before starting the identification of the honeys:

1. Observe the five samples. Without opening the bottles, ¿which similarities and which differences do you find between the bottles? Explain them
2. ¿Do you see any differences in color between them? ¿What do you think that it is the cause of these differences (in case you think there are differences)? Explain your answer.

Identification of the honeys

Using the organoleptic key and the information provided from the beekeepers:

3. Try to find out which is the anonymous honey. Why do you think is the anonymous?
4. Do you know from which plant does they come from? And who is the beekeeper of that honey? Justify your response based on the data provided and other information you got from your tasting analysis.

Part 2. What can you infer by observing the pollen?

There are two bottles with different pollen in the table. Observe them and answer the following questions:

1. What are the differences and the similarities between the two bottles?
2. Where do you think that these differences are attributed?
3. Relate the pollen with the honey and explain your choice
4. "Pollen is related with biodiversity". Develop your own explanation