Modeling in Pre-service Secondary School Teacher Education: developing an School Scientific Model of Energy

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Abstract. In this document, we will present the results of an investigation carried out in initial teacher education for pre-service secondary school Physics and Mathematics teachers in Chile. A Teaching and Learning Sequence (TLS) was iteratively designed following a Design-based research approach and implemented to promote the construction of an adequate School Scientific Model (SSM) of energy. This SSM is based on the well-known work on energy related concepts in physics education, including the ideas of energy degradation, conservation and transference. The methodology followed in the TLS is based on modeling and model-based inquiry. Subsequently, we have analyzed pre-service teachers’ qualitative productions to identify which model of energy they master at both the beginning and the end of the program. This allowed us to get hints of a learning progression in this field.

1. Introduction
The thermodynamic view of the world, based on the concepts of energy and energy-related ones such as work and heat [1], it is one of the most significant theoretical bases for the experimental sciences, engineering and other disciplines. The importance given in science education to energy is related to the integrative nature of this concept; its economic, social and environmental impact, and its presence in our daily lives. In school, energy and energy-related concepts are widely utilized due to its capacity to help us understand and address multiple phenomena of surrounding us [2-4]. As such, it is considered as one of the 10 big ideas of science that should structure compulsory education [5]. However, despite its importance, teaching energy presents a variety of difficulties.

Some of these difficulties are mainly associated with the polysem/ambiguity of the energy concept in both day and scientific language [2] [6-7], the multiple alternative conceptions about energy found in students, teachers and school texts [8-10], and the conceptual reductionism shown by some curricula, such as in the Chilean curriculum, where the thermodynamic vision of the world is reduced to the idea of energy transportation [11-12].

Based on the foregoing, there is an increasing interest in science and physics education to contribute to the adequate construction of a thermodynamic vision of the world based on energy and energy-related concepts for all educational levels, starting in initial teacher education. The final goal is for future teachers to develop the ability to understand their environment, have a critical opinion on the events happening in the world (e.g. the limitation of certain energy resources) and make reasoned and substantiated decisions (e.g. how to improve the efficiency of these available resources or find alternative ones), as well as acquire adequate tools for their teaching performance.

With this aim, we have designed a Teaching and Learning Sequence (TLS) based on the scientific practices framework [13-14]. The TLS is focused on the promotion of modeling practice [15-17] to build an adequate School Scientific Model (SSM) of energy for 12-16 years-old students. Subsequently, we have
analyzed the actual energy model that future Chilean Physics teachers have built during the implementation of this TLS, comparing their models at an initial and final moment. In this sense, our research question is:

How do the energy models of future physics teachers progress with the implementation of a Teaching and Learning Sequence focused on modeling?

2. Theoretical Framework

2.1. Models and the School Scientific Model of Energy

One perspective that has growing importance in the literature of science education research is that of relating the learning of science with the students' participation in school practices which are cognitively, socially and discursively analogous to those of the professional scientific endeavor [14] [16] [18]. Through participation in these scientific practices, students get to know how scientific knowledge is generated and validated, engaging in activities that promote scientific ways of thinking, doing and talking in the classroom [19]. In our context, the perspective of the scientific practices is known as the School Scientific Activity (SSA) approach [20]. Within this approach, the focus is in the students’ involvement in the scientific practice of modeling, supporting their progressive building of their own versions of key scientific ideas, referred to as School Scientific Models (SSM), starting from their own initial ones [21].

Model is a concept full of polysemy in science education, generally used to refer to the representation of scientific entities, such as objects, phenomena, ideas, processes or systems, which allow us to describe, explain and predict [21] [22]. From the semantic conception of scientific theories, scientific models are viewed as any representation that allows thinking, speaking and acting on a system of study [20]. As such, scientific models are considered the basic units of scientific reasoning [23].

According to the SSA perspective, the School Scientific Models (SSM) are the targeted, school-appropriate versions of the scientific models produced by science [17] [20] [24], which have been educationally reconstructed for the teaching and learning purposes [25]. These SSM are theoretical or conceptual in nature and include the abstract and central ideas of the disciplines that allow us to interpret different phenomena with the same way of looking at them [26-28]. As such, these SSM are similar to the “Big Ideas” or core concepts referred to in the literature [5]. For example, the SSM of matter as made of large amounts of “small parts” that can bond, which is appropriate for primary school children, helps them to look at and explain in a similar fashion two apparently different phenomena: for instance, how a cookie can be soaked in milk or how water can be made into ice.

With respect to the construction of a SSM of energy, there are different approaches to conceptualize energy at school. One of the most consensus proposal in the field of science education is the use of “energy-related concepts” proposed by Ogborn [1], based on associating energy to the state of a system and the ideas of transfer, degradation and conservation of energy. This well-known proposal is coherent with science and shows great potential to explain a wide range of phenomena in a compelling way which is especially useful for students and future science teachers [12]. Based on this approach, as referred to by different authors [1-3] [6-7] [29-30], in Table 1 we present the ideas that described the targeted SSM of energy that we used in this research. These ideas or SSM of energy were used for both designing a TLS oriented to the development of these ideas and analyzing the actual ideas of energy constructed by the future-to-be physics teachers (that is, the student-teachers’ own models of energy). It is important to clarify that there is not a hierarchy between these ideas, as they are all equally relevant for understanding and applying adequately the energy model to real phenomena.

In general, the ideas students hold and apply to the prediction or explanation of phenomena in thermodynamic terms are far from the ideas of the SSM described in Table 1. Students have mental models that are usually incomplete and quite different from the SSM that we target in schooling. A well-known example is students’ views of energy as a fuel that has very limited explanation power when dealing with the principle of energy conservation [2] [3].

Table 1: Current ideas of energy in primary school and the SSM of energy.

| Current Ideas | SSM of Energy |
|--------------|---------------|
|             |               |
| ...         | ...           |
When speaking about student-teachers, as we do in this study, research shows that pre-service secondary school teachers, like their future students, have generally a limited understanding of the SSM and do not hold an adequate model of energy [8]. For instance, rather than considering that energy is transferred from parts of the system to other parts by means of work or heat, both students and student-teachers usually explain phenomena in terms of energy transformation. An example from the student-teachers in this study can be found in Table 3 (see initial student-teachers’ quote, in italics, bottom-right), where an student-teacher explains the lighting of a LED in a mini-power station with the idea that potential energy is transformed into kinetic energy and then light. By doing so, student-teachers avoid to address what are the actual changes in the variables of the system, and as such, their “explanation” in terms of energy transformation does not actually explain what is happening [11].

With the appropriate educational support, however, the initial ideas of students and student-teachers (initial models) could evolve towards more sophisticated ones in terms of the targeted SSM. In fact, from a modeling perspective of conceptual development, science learning is understood as the evolution or progression of students’ ideas/models towards more sophisticated and scientifically coherent ones [15]. In the example of Table 3, the student teacher final model of energy, as inferred from his writing (see final student-teacher quote, in italics, bottom-left), uses a transfer-of-energy idea that makes explicit which variables are changing (e.g. appearance of a friction force-negative acceleration, increase in temperature, …). As such, his more sophisticated final model of energy in terms of energy transfer helps him to better explain the observed phenomena.

To promote the constructions of models in the classroom, several authors have proposed different cycles or modeling sequences for modeling-based instruction [31]. In this investigation we have been inspired by the cycle proposed by Couso and Garrido-Espeja [16], which differentiates the actions to be taken as a teacher in model-based instruction from the actual modeling practices expected by students. This cycle is composed of six instructional phases that demand students to: 1.-Feel the need to build a model, 2.- Express and utilize their initial model, 3.- Evaluate their model by testing it, 4.- Review their model by improving inappropriate aspects, 5.- Agree on a final model, and 6.- Apply the agreed consensus model to predict/ explain a new phenomenon. The TLS designed follows this instructional cycle, involving students in the modeling practices of Express their models; Use their models to describe, predict and explain phenomena; Evaluate their models by testing them empirically or theoretically and Revise their models of energy to improve their descriptive, predictive or explanatory power.

| SSM ideas | Description |
|-----------|-------------|
| Idea 1: Nature of energy (ES) | Energy is associated with the state or configuration of a system. When the state / configuration changes, the energy associated to the system changes. |
| Idea 2: Energy transfer (WQ) | Any change in the state/ configuration of a system/subsystem that entails an increase in its energy generates another change in another system/subsystem decreasing its energy (and vice versa). We call this energy transfer. These transfers can be made through work (W) or heat (Q) mechanisms. |
| Idea 3: Energy degradation (D) | Energy is irrevocably degraded along any process, by losing its quality. This means that energy has less capacity to generate new changes or that there is a decrease in the amount of usable energy of a system. |
| Idea 4: Energy conservation (C) | The amount of energy available is conserved (that is, it remains the same in quantity) in isolated systems. |

Table 1. Ideas of an School Scientific Model (SSM) of energy based on the “energy-related concepts” approach proposed by Ogbon [1].

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3. Method

3.1. Context and Implementation of the TLS

To analyze how do the initial student-teachers’ models of energy progress along a modeling-based teacher education intervention, a research-based TLS was designed and iteratively improved through three cycles of pilot testing, following a Design Based Research approach [11]. The implementation of the adhoc designed TLS included 4 sessions of 4 teaching hours (180 minutes each). Each session was focused on the understanding and explicit construction of each one of the ideas of the targeted SSM described in Table 1, following a progression from more concrete ideas (such as energy is not something in a system but a measure associated to the configuration and situation of a system, in session 1) to more abstract ideas (such as the conservation of energy in the session 4). This order of presentation of ideas was inspired by previous studies on learning progressions on energy [4] [32-33] that situate conservation and degradation at the upper anchor of an energy learning progression. Despite following the mentioned sequence, students’ were facing phenomena that required the application of all their ideas on energy, whether being those focused by the TLS or not. As such, in each teaching session the student-teachers applied their own ideas regarding all aspects of energy, hopefully progressively increasing their sophistication particularly on those aspects focused on in each teaching session. The chosen teaching and learning methodology for each session was model and modeling-based instruction, via the modeling cycle proposed by Couso and Garrido-Espeja [16].

The scheme of the TLS is shown in Figure 1. The complete TLS is available at [11]. Central activities of this TLS have also been published elsewhere [11-12].

![Figure 1. Structure of the Teaching and Learning Sequence (TLS) designed for the research. The complete TLS is available at [11]](image-url)

The first session of the teacher education course was devoted to the construction of the idea that energy is associated with the configuration and situation of a system, that is, the variables that define its internal state but also its movement and potential. (Idea 1 or ES). This idea is focused in overcoming inadequate views of energy as something material, some sort of “fuel” that gets into the objects or systems. It is an idea related to the fact that energy is an abstract concept that we associate to an object or system.
depending on its configuration (internal energy) and situation (kinetic and potential energy). As such, this idea helps students to focus on the variables that describe the configuration and situation of the system, instead of in energy forms. The aim is to associate energy changes with the changes in these variables that describe the “state” of the system: changes in velocity, temperature, pressure, height,… In this session, teachers were asked to identify, in the context of waterpower-plants, what possible different “states” (configurations and situation) a system could have, how we associate energy to these diverse “states” and what possibilities do they have to trigger useful changes for us. A guiding question was “if water “with more energy” (such as water at high temperature at the top of a DIY waterpower station) will produce more movement of the turbine and more lighting of the attached LED than water at room temperature. The purpose of the discussion was to associate energy to the variables that describe how the system is (and not what it has), and to think in terms of profitable or not so profitable configurations of the system. The student-teachers could test their ideas measuring the voltage generated in different situations: room temperature water, sugary water and heated water falling from different heights. Questions to students were focused on describing how the system was, in terms of its variables, before and after, to help them identify what changes were happening and realise that absolute measure of energy is impossible. The focus was also in the energy chain in each stage of the phenomena, for instance asking what happens with the energy from the moment water is contained in a great height to the moment something in the central starts to spin.

In the second and third sessions the future physics teachers were supported to develop an energy-transfer view of the changes of a system, overcoming their initial explanations in terms of energy forms and energy transformation. In the second session the student-teachers were asked to predict, measure and discuss thermal changes in the context of lunch boxes. They analysed the impact in the energy transfer by means of heat of 1) the use of different conducting or isolating materials, 2) the degree of variation of temperature and 3) the size of the contacting surfaces. In the third session they predict, measure and discuss about motion changes in the context of colliding mobiles. By analysing the energy change in the observed elastic and inelastic collisions and comparing it with the theoretical analysis of the present forces, the future teachers were able to identify which variables affect energy transfer by means of work. By using a scaffolding table, they had to think in terms of what variables were changing in every situation and to what main transfer mechanism, either by means of heat or work, did they associate the energy transfer taking place.

A final session was focused on the analysis of energy chains in terms of degradation and conservation of energy. To do so, they had to describe the path followed by energy from the moment a wheel is made to go round until the brake stops it, making measurements of temperature change in the braking disc during the process. Students were asked to describe in a qualitative manner where the energy is in every step of the process and to estimate in a quantitative manner how much energy there were in every part of the system, given a concrete value to the initial energy of the wheel. Through questions such as “What is the energy path from the moment the wheel is going round till the wheel is stopped and the brake disk is not incandescent anymore? What can you do with the energy dissipated to the environment at each stage of the process? How much energy must be at the end?, the student-teachers are given opportunities to identify energy transfers, the mechanisms of energy transfer and how in spite of the conservation of energy its quality and utility is reduced along the process.

3.2. Data collection and analysis
The research undertaken is of a qualitative-interpretative nature with a transforming perspective, since its obtained results have the purpose of influencing an existing course of initial teacher education in Chile. The participants of the study were 22 second-year pre-service physics teachers. The collected data consist of the written multimodal productions of pre-service teachers, including textual explanations, drawings and schemes from their worksheets. In each session, despite working with student-teachers in the construction of an idea of the SSM of energy (e.g. transfer of energy), the teaching and learning activities were contextualized on diverse phenomena (e.g. energy transfers in a hydroelectric power station or in the braking system of a car), which allowed for different student-
teachers’ productions regarding each idea of the SSM at different moments of the teacher education intervention.

To analyze the evolution of the student-teachers’ ideas, their models of energy were identified at an initial and at a final moment of the TLS. To characterize their models of energy, we use a system of categories that describe the different ‘stages’ of development and sophistication of each idea of SSM that can be inferred from the student-teachers’ answers at different moments along their training. Each stage suggested the particular way of understanding an aspect of the energy SSM of Table 1, from a low level of understanding (stage 1) to holding an adequate view in terms of the SSM (stage 4). These stages for each idea of the SSM of energy were constructed combining research literature on the teaching and learning of energy and a preliminary analysis of the qualitative productions of the future Physics teachers (Table 2), done both in this and also in a previous research [4].

Table 2. Stages for each idea of the SSM of energy.

| Level | Nature of energy                                      | Level | Transfer of energy                                           |
|-------|-------------------------------------------------------|-------|-------------------------------------------------------------|
| ES4   | Energy is associated to the change in configuration and situation or “state” of a system | WQ4   | In a change energy is transferred from one system to another or from parts of a system to another by means of work and heat. |
| ES3   | Energy is associated to the configuration and situation or “state” of a system          | WQ3   | Energy is transferred from one system to another or from parts of a system to another, identifying aspects related to work or heat. |
| ES2   | There is energy in systems and it causes its “state”                                       | WQ2   | Energy is transferred from systems to other systems or from parts of a system to other parts. They can mention how certain devices power these transfer. |
| ES1   | Objects/systems have energy.                          | WQ1   | Energy transforms from one form to another. It also could be that heat, forces or work are transferred too. |
|       |                                                       | WQ0   | Changes are produced by mechanical agents like friction.    |

| Level | Energy degradation                                      | Level | Energy conservation                                         |
|-------|---------------------------------------------------------|-------|------------------------------------------------------------|
| D4    | Energy gets degraded as a system keeps losing its potential to generate new changes. When energy gets degraded, its usefulness is diminished. | C4    | The total amount of energy is conserved, in such a way that the energy increased or decreased in a system corresponds to decreases or increases of energy in other systems or the environment. |
| D3    | Energy is less profitable to generate new changes, as it has been dissipated.                          | C3    | The total amount of energy is conserved, but there is not recognition of increases or decreases of energy in other systems or subsystems. |
| D2    | Energy gets dissipated along an energy chain.                                                     | C2    | The total amount of energy is not conserved, as some energy is dissipated along the energy chain. |
| D1    | Energy is not seen as less useful along an energy chain.                                              | C1    | The total amount of energy is not conserved. Some energy is lost or gained. |

In Table 3 we show an example of how this analysis was done. For any particular idea of the SSM of energy we have identified questions used in the TLS which addressed that idea in different contexts. Table 3 includes a quote of the actual answers given to those questions by a concrete pre-service teacher (S4) both at an initial (left) and final (right) moment. From this and other answers of this particular teacher, we have inferred at what stage that teacher masters a particular idea of the SSM of energy (in this case, Idea 2 or WQ). For instance, the stage at which the student teacher masters the idea of energy transfer at an initial moment is stage 2 of the idea: the stereotypical view of energy transformation between potential and kinetic energy (WQ2). In a final moment, however, the teacher is able to explain
an analogous phenomenon using an idea of energy-transfer by means of heat and work in an adequate way, which corresponds to stage 4 of this idea (WQ4).

In this analysis, each category was named including a reference to the idea of the SSM of energy that is addressed and its level of sophistication, from 1 to 4. For example, ES1 is used to code a view of the Idea 1 of the SSM of energy (idea of nature of energy or ES) at a level or stage 1: thinking that energy is something / a kind of fuel present in things. A real example would be a student-teacher stating S1 “we use the energy of the water to move the turbine”. ES3, however, refers to a view of the same Idea 1 of the SSM of energy (ES) at a higher level of understanding or stage 3. An example of another student-teacher holding that idea ES3 is one that states S4 “We take advantage of the state of the water: its capacity to flow and the height of it. It depends on what we use the energy for. Although hot water is very energetic, for the purpose that we use it, it does not increase the voltage”.

For the intra-rater reliability of this analysis, the entire corpus of answers was coded by first author at two different times. For inter-rater reliability, the second author coded independently a proportion of the student-teachers’ answers, including particularly those where the first researcher had doubts. Any discrepancy was solved and decisions on how to attribute stages in case of conflict were made explicit in the complete analysis [11].

**Table 3. Example of how the answers of a student-teacher were coded in terms of stages of sophistication/development for each idea of the targeted SSM of energy, both at an initial and final moment of the teacher education course.**

| Initial moment | Final moment |
|----------------|--------------|
| Context in the TLS | Energy transfer in a Formula 1 car when it is braking and there is lighting of the brake discs |
| Question | Which is the path followed by the energy associated to the lighting of the brake discs in the car wheels, from the initial movement of the wheel until the moment the car is stopped, and the brake discs stop shining? |
| Quote of an student-teacher | S4 “The energy is in the auto-motor system, which combuts benzene. Through work, the movement of the car is obtained, displayed as kinetic energy. When braking, that energy is transferred to the brake disc through work, since a friction force is generated between the metals stopping the car and causing the agitation of the particles, and an increase in temperature, then it is transferred to the environment through heat” |
| Stage of the energy model | Idea of energy transfer through work and heat (WQ4) |

After categorizing the stage of the model of energy of each pre-service teacher for each idea of the SSM at the beginning and at the end of the teacher education sessions, we carried off a graphic representation inspired by the logic of learning progressions [16] [23] to identify the evolution of the ideas of future teachers regarding the SSM of energy targeted in the TLS.

In this graphic representation (See Figure 2) there are colored spheres the size of which represent the amount of pre-service teachers whose models of energy, for each idea of the SSM of Table 1, are in each stage of sophistication from 1 to 4, at both an initial (I) and final (E) moment of the teacher education course.

In Figure 2 a grey dotted line separates the ideas that compose the SSM of energy. In purple colors we represent the stages of the idea of energy associated with the state of a system (ES); with blue colors
the idea of transfer of energy (WQ); with yellow colors the idea of degradation of energy (D); and with orange colors the idea of conservation of energy (C).

Stages of the energy model from initial ideas to ideas closer to the SSM are represented by numbers in the Y axis, from 1 or less sophisticated to 4 or more sophisticated versions of the pre-service teachers’ model of energy. There are also spheres at level 0 to categorize when a future teacher describes the phenomena without talking about energy (e.g., utilizing only mechanical concepts). In the event that the ideas of a future teacher, as they appear in their written productions, cannot be categorized on any level this is represented with another sphere in a position lower than level 0 on the X axis.

Each vertical column of Figure 2 include spheres with numbers that add to 22 (total amount of student-teachers) because they represent the stages of the model of energy in which we can categorize the answers of all future teachers, at a given initial or final moment, regarding each of the ideas of the SSM of energy of Table 1. With a dotted line of the same color we represent the evolution in the level of sophistication of the model of energy we can infer by seeing in which stage are the majority of students at the beginning and end of the teacher education course.

4. Results
The evolution graphic of the pre-service teachers’ model of energy (see Figure 2) let us identify not only the level of success of the TLS and teacher education course in terms of learning, but also which were the simplest and most complex ideas of the SSM to be developed by future teachers.

The idea of the SSM of energy that associates energy with the state of a system (ES) was an idea that was mastered by pre-service teachers from the initial moment of the TLS, as their productions show quite sophisticated stages from the beginning of the training. By the end of the TLS, this is an idea that most pre-service teachers’ hold, with more than 70% of teachers using this idea in their productions with the maximum stage of sophistication (16 in ES4).

When talking about the idea of energy transfer (WQ), we see that at the beginning of the TLS a vision of energy transformation (8 in WQ1) and a vision of transfer of energy between the parts of a system predominated in pre-service teachers’ productions, without identifying any mechanism for this transfer.
of energy (12 in WQ2). Nevertheless, at the final moment of the TLS, the idea that more noticeably have evolve was this one. Most of future-to-be physics teachers (17) explained phenomena referring to both mechanisms of energy transfer, and 5 more could explain the presented phenomena identifying at least one of the energy transfer mechanisms, either work or heat. Thus, all of the pre-service teachers reached sophisticated stages of the model of energy regarding the idea of energy transfer.

Regarding the idea of degradation of energy (D), at the beginning of the TLS many (14) pre-service teachers just mentioned aspects associated with the dissipation of energy (D2) and 8 do not mention aspects associated with the degradation of energy at all. At the end of the TLS, we can infer from the pre-service teachers’ answers that 13 pre-service teachers identify a lower utilization along the processes, attributing this cause to the dissipation of energy (D3) and even 7 more identify that energy degrades as a system loses its capacity to generate new changes and usable energy decreases (D4).

Finally, results in Figure 2 show that the idea of the SSM of energy less constructed by pre-service teachers was that of energy conservation (C). In student-teachers’ initial answers this idea only appears in the responses of some of them, when mentioning that in the discussed phenomena energy is not conserved because it is lost (3 in C1) or not preserved because it dissipates (4 in C2). At the final moment of analysis, however, almost half of the pre-service teachers (10) are able to mention the idea of energy conservation in their explanations, but they do not identify that the dissipated energy corresponds to the gain of energy in another system/subsystem or the environment (C3) and only 2 pre-service teachers are able to reason in terms of the more sophisticated stage of the idea of energy conservation.

5. Summary and Conclusion
Participation in scientific modeling practices, through the designed TLS, contributed to the future-to-be teachers’ progression from naïve to more sophisticated versions of the energy model, with their understanding of energy increasingly approaching the desired SSM of energy.

The idea that had a major evolution was the one related with energy transfer (WQ), with pre-service teachers’ explanations of phenomena evolving from being in terms of energy transformations from one type of energy to another, to recognizing the transfer of energy between systems through the mechanisms of heat and work. We consider that the fact many teachers show from the beginning very sophisticated responses regarding the idea about the nature of energy (ES) was helpful in this case. Despite the complexity of associating energy to the state of the system, the approach of the TLS, in which future teachers were strongly guided to describe the configuration of the systems and the changes they experienced, seems helpful in conveying the way of thinking necessary for the targeted SSM.

The second idea that showed an important improvement was the degradation of energy. However, despite the fact that the great majority of future teachers went from not mentioning aspects related to energy degradation to start mentioning them in their explanations, the evolution they had does not achieve what we expected. This is an idea of the SSM that several authors consider intuitive and simple to build. However, in our results, future teachers identify the degradation of energy -mostly- as energy transferred to air that cannot be used. These results are consistent with the study by Pinto et al [9] and point out the importance of deepening the teaching and learning of this idea by including processes associated with the degradation of energy beyond mere dissipation.

Finally, the idea of conservation of energy, despite being one of the most transmitted ideas throughout traditional schooling, was the most difficult idea to build because both its abstraction and the fact that it contradicts everyday life phenomena in which the degradation of energy is evident. Nor is there a wide range of paradigmatic phenomena that we can use to enhance its construction, since it is a theoretical principle that we cannot actually experience in real life. In fact, the best results associated with this idea emerged in explanations made by pre-service teachers after using theoretical analogies [28], because through them students interpreted and explained phenomena without experimenting them in real life.

Our results showed differences in how the SSM ideas are developed by pre-service teachers. Despite the TLS proposed included scaffolding artifacts, diversity of contexts, a variety of learning opportunities related to modeling and similar cognitive demands for each idea, it seems not enough to develop a
balanced SSM of energy. Pre-service teachers' performance revealed that ideas of conservation and degradation of energy are more abstract and require other learning opportunities. This signals the importance of decomposing the targeted SSM of energy into different ideas that can be addressed together but also separately to emphasize those that represent more difficulty. Despite all pre-service teachers can say at the beginning of the teacher education course that “energy is conserved”, they will not use this idea to model their world (describe, predict or explain it) if we do not find situations that make necessary its explicit use.

In summary, we consider essential that future teachers have a solid foundation of the key SSMs that they should teach in the classroom, as was the case of the SSM of energy. However, student-teachers’ learning of this disciplinary knowledge does not guarantee that they will use it properly in their future classrooms. In that sense, this research shows only the part of the teacher education devoted to content knowledge, but not how their pedagogical content knowledge was also addressed by explicitly reflecting on the modeling-based instruction they followed and the learning they acquire with it.

6. References

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