Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: A Ezquerra and I Ezquerra-Romano 2019 *J. Phys.: Conf. Ser.* **1287** 012038

IOP Conf. Series: Journal of Physics: Conf. Series **1287** (2019) 012038 doi:10.1088/1742-6596/1287/1/012038

Using neuroscience evidence to train pre-service physics teachers on the concepts of heat and cold

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Abstract. Teachers must identify, manage and modify alternative conceptions in their students. However, research consistently highlights that future teachers prioritise disciplines' requirements rather than the educational needs of children. Moreover, some researchers have proposed that the way our senses work shapes the development of children's ideas. Neuroscientists have only recently started to understand how the senses transduce and transmit stimuli. In this study, we show an innovative initial training course of Didactics of Physics, which includes the latest understanding of the thermosensory system. We analysed the progression of the educational proposals written by future teachers. This analysis revealed the effect of integrating neuroscience contents in the initial training. We found that the neuroscience insights helped future teachers incorporating children's misconceptions in their proposals. Additionally, they lowered their expectations and became less frustrated. They understood that it is not expected to quickly modify pupils' alternative conceptions because they have a physiological component.

1. Introduction

Friedrichsen, Van Driel and Abell [1] grouped the possible educational orientations into two main approaches: those which focus on teachers (also called traditional, transmissive or teacher-based orientations) and those which focus on pupils (also called alternative or student-based orientation). Studies consistently highlight that future teachers prioritise disciplines' requirements rather than the educational needs of students [2]. Moreover, future teachers are initially unsure about: how to choose and organise the educative objectives, what science themes are most appropriate for their pupils, what teaching sequences to follow and how to evaluate their pupils [3,1]. These initial doubts predispose future teachers to use the structure of the scientific discipline as a reference for teaching, because they feel more confident with this knowledge. Consequently, teacher-based orientations are the starting point of training courses [4,5]. Another factor that contributes to teachers' initial approach to education is the personal internalisation of their experience as students [6]. All together, these doubts and factors contribute to the notion of what a good teacher is [7]. It results in very stable notions on how to teach, which hinder the incorporation of innovative ideas [8].

Future teachers need to have a deep and integrated knowledge of foundational science concepts and principles. Additionally, "they also need to have scientific practices, Nature of Science (NoS), and pedagogy, as well as take a metacognitive stance towards their teaching, in order to expertly engage their students in science practices" [9]. This set of professional knowledge "goes beyond knowledge of subject matter *per se* to the dimension of subject matter knowledge for teaching" [10]. In the literature, this has been called Pedagogical Content Knowledge (PCK). PCK determinates a genuine form of knowledge, which distinguishes teachers from other professionals in the fields of education and pedagogy [11].

Although the precise characterization is still an open issue, the key elements of PCK are: knowledge of representations of subject matter by teachers, and knowledge of students' conceptions and their specific learning difficulties [12]. Therefore, in the context of PCK, teachers must develop a broad set of skills to facilitate learning in their pupils [13]. Thus, it is not effective for future teachers to solely know the list of alternative conceptions held by high school students. Teachers should know, identify, manage and modify alternative conceptions in their pupils. They should adapt teaching strategies, the science curriculum, and the evaluation of the learning and teaching process accordingly. They also need to define the educational goals and the approaches in science teaching [3].

Furthermore, some researchers have proposed that the way our senses work shapes the development of children's ideas [14,15,16]. At the time this was first suggested, little was known about the neurophysiology of our sensory organs. We have only recently started to understand how the senses transduce and transmit external information [17]. Importantly, this transformed information is the basis to construct and develop concepts [18]. Thus, in this study, we investigated whether understanding how sensory organs work might help future teachers integrating students' concepts in their teaching proposals. We analysed the progression of educational proposals about heat and temperature that were developed by future teachers. This revealed the effect of integrating neuroscience contents in the initial training of secondary schools' teachers.

2. Course Design and Method of Analysis

The study was carried out in the context of a constructivist-oriented training program on how to teach physics in secondary school. It was a 45-hour course from September 2016 to January 2017 (18 weeks) that included 36 future teachers which were grouped into 6 teams.

In accordance with the theoretical framework discussed above, we tried to go beyond knowledge of subject matter *per se* and reach the dimension of subject matter knowledge for teaching [10]. We followed a strategy along the same lines of what Abell, Appleton & Hanuscin [19] called Reflection Orientation. Thus, future teachers had to do a first proposal to teach the topic 'Heat and Temperature' at Secondary schools. They had to: select and organise the educative objectives, propose a teaching sequence, and consider how to evaluate their pupils [3]. Proposals on the same topic were analysed and repeated at different points during the course.

This approach to teach future teachers started from a typical professional problem: the preparation of a proposed topic. The aim was to trigger a reflection on their educational vision and its consequences. Thus, we posed a professional situation and looked for promoting a metacognitive stance towards their own teaching [9]. This should also equip them with the necessary skills to analyse future problems and apply their theoretical knowledge [13].

The course was organised around three theme blocks: Physics as a subject of teaching, Physics in the Secondary Education Curriculum (objectives, contents, methodology and evaluation criteria), and Physics Proposals in Secondary Education (activities, resources…).

Theme block 1. Physics as a subject of teaching.

- Professional knowledge: What should a Physics teacher know and be able to do? *(proposal 1).*
- Learning theories: Constructivism and Alternative Conceptions in Physics (in this stage, only the general characteristics of alternative conceptions in sciences were explained) *(proposal 2).*

Theme block 2. Physics in the Secondary Education Curriculum: objectives, contents, methodology and evaluation criteria

- Physics' curriculum in Secondary Education.
- How to design a course of Physics? How to design a didactic unit of Physics?
- How to evaluate based on normative criteria?

Theme block 3. Physics' Proposals in Secondary Education: activities, resources…

- Didactic proposals of Physics in secondary school: Science, nature of science; Mechanics and Thermodynamics and Energy *(proposal 3)*; Electricity and Magnetism; Light and Sound; Quantum and Relativity and final of course *(proposal 4)*.
- Didactic resources for teaching: ICT, videos, apps, etc.

Block 1 and 2 were carried out during the first three weeks of the course. In this period, future teachers were taught the basics of professional knowledge and learning theories.
In block 3, future teachers learnt how to apply all this knowledge on different topics (Nature of science, Mechanics…). The aim in this block was to encourage future teachers to understand, reflect and discuss the learning difficulties and the alternative conceptions observed within each topic [19].
In summary, future teachers were asked to submit their education plan on 'Heat and Temperature' 4 times: at the beginning of the course (proposal 1), after the topic 'Alternative Conceptions in Physics' (proposal 2), after the topic 'Thermodynamics' (proposal 3), and at the end of the course (proposal 4).
The educational proposals consisted of 5 parts: *Introduction*, where they had to show their approach to science teaching; *Objectives*, in which they defined the educational goals; *Contents*, where they defined the theoretical content; *Activities*, in which they described the sequence of learning process, and *Evaluation*, where they proposed the way of evaluating the learning process [3].
All proposals were discussed and evaluated by the entire class. This educational strategy required each team to reflect on their own educational proposal and contrast it with the rest of the groups [19]. This should stimulate a metacognitive stance towards their own teaching [9].
To analyse the progression of future teachers, we identified the units of information about alternative conceptions and neuroscience knowledge that were included in each proposal. The presence of words, expressions or sentences, which contained ideas about Alternative Conceptions (AC) or Neuroscience (NS), were used as criteria to identify units of information. The existence or not of units of information in each proposal allowed us to observe the evolution of future teachers' proposals throughout the course. Since the 4 submitted proposals were on the same topic, we could compare on the same basis the new contents, details and considerations included in each proposal.

3. Results

3.1. Proposal 1
This first proposal was both requested and submitted at the beginning of the course, while future teachers were working on the topic 'What Should a Physics Teacher know and be able to do?'. At this stage, future teachers only had their experience as students. This proposal was considered as the starting point that teachers had on how to teach.
Some groups considered using the previous ideas of their future pupils, but as we explain below this approach was very superficial. Additionally, none of the proposals incorporated any neuroscience content.
In the section *Introduction*, groups outlined the general approach of their proposals. In particular, some of them discussed the importance of the topic 'Heat and temperature' in Physics. Others explained why it is useful to understand the phenomena for everyday life, while most groups simply mentioned that these topics are in the official curriculum. In this first proposal, two groups highlighted that pupils could have "false ideas" about heat and temperature (e.g., G2: "These concepts [heat and temperature] are misused every day. This can cause that our students develop misconceptions").
The sections *Objectives* and *Contents* should be a more detailed account of what is outlined in the *Introduction*. However, none of the proposals included any units of information about alternative conceptions in these sections.
In the sections *Activities* and *Evaluation*, only Group 4 considered the previous ideas of students. In particular, they proposed a debate where children would compare and contrast their own ideas on heat

and temperature. They also planned how to evaluate whether pupils have replaced their old ideas with the new content and if they had learnt to distinguish between the two concepts: heat and temperature.
In summary, although some future teachers showed an intention to consider students' ideas, these statements lacked didactic rigor. Thus, there was not thread of reasoning supported by theoretical knowledge, but a disordered set of intentions. Furthermore, they did not implement it in a specific educational intervention. In fact, the proposals focused on scientific concepts and the contents were chosen and arranged according to the discipline. Therefore, as found in previous studies, the transmissive orientations were the starting point of our future teachers [4,5]. These first proposals were used to determine the initial view of our preservice teachers and to establish the baseline of our analysis.

3.2. Proposal 2
The second proposal was both requested and submitted after delivering the topics: Constructivism and Alternative Conceptions in Physics. In this phase, more groups incorporated the previous ideas of pupils in their educational proposals, but mainly in the section *Introduction*. This indicates that students considered including alternative conceptions but failed to expand on it in other sections. Additionally, none of the proposals included any neuroscience-related units (see Table 1).

Table 1. Units of information found in proposal 2. Alternative Conceptions (AC); Neuroscience (NS).

Group	Introduction	Objectives	Contents	Activities	Evaluation
G1	AC ---	--- ---	--- ---	AC ---	--- ---
G2	AC ---	AC ---	--- ---	AC ---	AC ---
G3	AC ---	--- ---	--- ---	--- ---	--- ---
G4	AC ---	--- ---	--- ---	AC ---	--- ---
G5	--- ---	--- ---	--- ---	--- ---	--- ---
G6	AC ---	--- ---	--- ---	--- ---	--- ---
TOTAL Proposal 2	5 group, AC ~~NS~~	1 group, AC ~~NS~~	~~AC~~ ~~NS~~	3 group AC ~~NS~~	1 group AC ~~NS~~

In the *Introduction* section, five groups indicated that they would apply the constructivist theory. They expressed that they would find out what previous ideas about heat and temperature are held by the children. They also claimed that they would try to trigger a conceptual change in their pupils. The following statements are quotes obtained directly from the proposals, G4: "…students are not blank sheets on which we can write lessons."; G3: "…previous ideas held by students about these topics will be found with games."; G2: "Our intention is to disassemble those alternative conceptions".
In the *Objectives* section, G2 indicated that they would first look for children's ideas. Then, they would try to deconstruct them in order to tailor pupil's ideas about heat and temperature.
In the section *Contents*, none of the proposals incorporated any of the considered units of information.
In this instance, the *Activities* section seemed to maintain certain consistency with the *Introduction*. Thus, some teams planned activities to look for alternative conceptions of pupils (e.g., G1 and G2 indicated "exercise 1: initial questionnaires to extract previous ideas" or G6 proposed a "debate with the pupils about the use of heat and cold in the language").
Only Group 2 considered students' ideas in the *Evaluation* section. In particular, they proposed a final questionnaire similar to that mentioned in the section *Activities* (see above). The aim of this

questionnaire was to make children realise about their own conceptual change by encouraging them to compare and contrast their initial and final ideas about heat and temperature.

3.3. Proposal 3

The third proposal was requested and submitted after delivering the topic: Thermodynamics. The analysis shows that each group increased the integration of pupils' previous ideas in their proposals, especially in the section *Activities* (see Table 2). Remarkably, some groups indicated that eliminating alternative conceptions is a very difficult or unsolvable problem.

Table 2. Units of information found in proposal 3. Alternative Conceptions (AC); Neuroscience (NS).

Group	Introduction	Objectives	Contents	Activities	Evaluation
G1	AC	---	---	AC	---
	NS	---	---	---	---
G2	AC	AC	AC	AC	---
	NS	---	NS	---	---
G3	AC	---	---	AC	---
	NS	---	---	NS	---
G4	AC	---	---	AC	---
	NS	---	---	NS	---
G5	AC	---	---	---	---
	NS	---	---	---	---
G6	AC	---	---	AC	---
	NS	---	---	---	---
TOTAL	6 group, AC	1 group, AC	1 group, AC	5 group, AC	~~AC~~
Proposal 3	6 group, NS	~~NS~~	1 group, NS	2 group, NS	~~NS~~

The *Introduction* section showed a significant change compared to previous proposals. In this occasion, every group stated that they should analyse alternative conceptions about heat and temperature that are held by their children. They also claimed they would aim at triggering a conceptual change in their pupils. Furthermore, they all indicated that it was useful to understand the potential neurophysiological component of alternative conceptions. For instance, G1 commented that “we have to be aware of the difficulty of extinguishing alternative conceptions, because they are created by the structure of our physiology” and G2 highlighted that “they [alternative conceptions] are unavoidable, so we must take them into account when we consider the methodology and, even, our attitude”.

In the *Objectives* section, G2 commented again that they would first find out children’s ideas. Then, they would try to deconstruct them in order to tailor pupil’s ideas about heat and temperature. In this instance, G2 incorporated units of information about alternative conceptions and neuroscience knowledge in the *Contents* section. In particular, this group mentioned that students should be taught about how our senses seem to mislead us; this is, the relationship between our perception and the physical concept of heat.

The *Activities* section also experienced a significant change. Five groups proposed to identify children's misconceptions. Additionally, they also indicated that they would make use of the bibliography on alternative conceptions. Furthermore, two out of five groups attempted to modify the typical activities on thermology according to how our senses work. In particular, they proposed questions such as why metals are felt as if they were colder than other materials and at what temperature do I start feeling cold (or hot). They also suggested an activity with three containers of cold, warm and hot water. It seems, therefore, that these groups tried to bring together sensations and theory. They also suggested that this could facilitate children's learning (e.g., G4 proposed a debate “to arise alternative conceptions" and G6 considered to analyse "misconceptions in language". In the *Evaluation* part, none of the proposals incorporated units of information about alternative conceptions nor neurosciences.

3.4. Proposal 4

The fourth proposal was both requested and submitted at the end of the course. The groups showed a significant incorporation of alternative conceptions in every section of the proposals. Neuroscience content was also included in more sections, especially in the *Introduction* and *Objectives* sections (see Table 3). Moreover, the proposals tried to establish links between both topics.

Table 3. Units of information found in proposal 4. Alternative Conceptions (AC); Neuroscience (NS).

Group	Introduction	Objectives	Contents	Activities	Evaluation
G1	AC NS	AC NS	--- ---	AC ---	AC NS
G2	AC NS	AC ---	AC NS	AC NS	AC NS
G3	AC NS	AC NS	--- ---	AC NS	--- ---
G4	AC NS	AC NS	AC NS	AC NS	AC NS
G5	AC NS	--- ---	--- ---	AC ---	--- ---
G6	AC NS	AC NS	--- NS	AC ---	--- ---
TOTAL Proposal 4	6 group, AC 6 group, NS	5 group, AC 4 group, NS	2 group, AC 3 group, NS	6 group, AC 3 group, NS	3 group, AC 3 group, NS

In the *Introduction* part, all groups highlighted that they would apply a constructivist-based model of teaching. They also indicated that it was useful to know the possible neurophysiological origin of alternative conceptions and they mentioned that this should be considered by teachers. Additionally, G2 explained that it is impossible to completely eliminate alternative conceptions, because they have a physiological component. G4 indicated "We should not forget that, even though our students might understand the concept of heat as energy transfer, they will always experience *hot* or *cold* whenever they check an object's temperature". Most groups included similar statements in their proposals. These results show an attempt to establish links between the topics of alternative conceptions and neuroscience.

The *Objectives* section changed substantially compared to previous versions where units of information were barely included. Every group, except for G5 and G2, indicated that children should be taught the possible neurophysiological component of alternative conceptions, because this would help them understanding factors that hinder their own learning process. G2 said: "… students must reflect on their learning process, on the trajectory from preconceptions to new concepts". However, G5 appeared to consider that only academic topics could compose curriculum objectives.

In the *Contents* section, G2, G4 and G6 proposed some neuroscience questions that students should understand. These questions focused on students' views about heat and temperature (e.g., G4: "Distinguish between the sensations of "cold" and "heat" and the corresponding scientific concepts"). Furthermore, G2 and G4 proposed some alternative conceptions on heat and temperature to be included as teaching contents. The other groups only considered academic topics: the contents on physics of a traditional scholar curriculum.

Furthermore, every group proposed several *Activities* to detect children's alternative conceptions. They detailed the specific alternative conceptions that they were aiming at tackling with each activity. G2, G3 and G4 designed activities to compare sensations with scientific measures. For instance, G2 proposed an activity to discuss the thermal perception of metal and wood, and an experiment with three water buckets at different temperatures. They claimed that they would bring together scientific data (for instance, water at 20ºC) and sensations to help children overcoming alternative conceptions.
In the *Evaluation* section, G1, G2 and G4 indicated the necessity to add neuroscience details in the explanations of natural phenomena. They suggested that students should understand the differences between thermal concepts (heat and temperature) and how we feel them. Exam's activities proposed by future teachers were similar to those suggested in the other parts of their proposals. In particular, G1 indicated that "children have to differentiate between scientific data and how we feel hot or cold" as one of their evaluation criteria. Furthermore, G2 mentioned that children should learn to recognise the differences between previous and new learnings (the conceptual trajectory). The rest of the groups did not consider these topics. Therefore, they continued to propose academic criteria to evaluate.

4. Discussion

Consistent with previous studies, our future teachers were initially prone to value, select and organise their proposals conforming to a discipline vision [20,5]. Thus, the children's ideas were poorly incorporated in the first proposal. Future teachers' integration of the children's needs was disjointed in their proposals. These results suggest that, at the beginning, most trainees believed that they only need to teach scientific knowledge in an intelligible way to pupils [21].
In the second proposal, preservice teachers started to adopt a constructivism approach. Most of them began to consider alternative conceptions, but only as a list of the typical mistakes made by secondary school students. However, addressing children's ideas is much more complex than knowing a mere list of errors [16]. Therefore, our future teachers did not deal effectively with alternative conceptions at this stage. However, some of them started to plan activities to detect and overcome children's misconceptions (see Table 4).

Table 4. Units of information of AC and NS found in each section and proposal.

	Introduction	Objectives	Contents	Activities	Evaluation
Total groups Proposal 1	2 groups, AC ---	--- ---	--- ---	1 group, AC ---	1 group, AC ---
Total groups Proposal 2	5 groups, AC ---	1 group, AC ---	--- ---	3 groups, AC ---	1 group, AC ---
Total groups Proposal 3	6 groups, AC 6 groups, NS	1 group, AC ---	1 group, AC 1 group, NS	5 groups, AC 2 groups, NS	--- ---
Total groups Proposal 4	6 groups, AC 6 groups, NS	5 groups, AC 4 groups, NS	2 groups, AC 3 groups, NS	6 groups, AC 3 groups, NS	3 groups, AC 3 groups, NS

In the third proposal, a significant progression in the application of misconceptions was observed, which was concomitant with the introduction of neuroscience content (Table 4). Importantly, some groups reported that alternative conceptions are difficult or impossible to extinguish and they attempted to explain this with neuroscience content. This approach to teaching and learning seems to be more realistic and mature. This change appeared to be catalysed by the incorporation of neuroscience contents, as indicated by their claims.
In the last proposal, all groups used alternative conceptions in the *Introduction* and the *Activities* part. They even specified how to use these ideas in each activity. Moreover, the neuroscience knowledge also appeared in the *Introduction* section of every final proposal. All of them indicated that teachers should know the possible neurophysiological component of alternative conceptions, because this

would help them understanding children's learning difficulties. These statements indicated the importance that they gave to these topics.
As indicated by Duschl, Maeng and Sezen [22], it is relevant to study the evolution of hypothetical paths or itineraries of progression. This type of analysis is considered of great importance, because it helps understanding the learning progression of trainees regarding PCK [23, 24]. To analyse the evolution of the understanding and application of both topics (alternative conceptions and neurosciences), we examined the timing of appearance throughout the proposals. Table 5 shows the sequence of incorporation of units of information on alternative conceptions throughout the four proposals for each group. If the units of information on misconceptions appeared for the first time in two or more sections within the same proposal, we arranged the sequence according to the frequency of appearance in each section.

Table 5. Sequence of incorporation of alternative conceptions throughout the proposals. Introduction (I), Objective (O), Contents (C), Activities (A) and Evaluation Criteria (E).

Groups	Proposal 1	Proposal 2	Proposal 3	Proposal 4	Sequence of incorporation
G1		IA	IA	IAOE	IAOE
G2	I	IAOE	IAOC	IAOEC	IAOEC
G3		I	IA	IAO	IAO
G4	AE	AI	AI	AIEOC	AIEOC
G5			I	IA	IA
G6	I	I	IA	IAO	IAO

Although each group had their own timing, most of them showed a similar sequence of incorporation of alternative conceptions. In particular, most preservice teachers added this topic (AC) to their proposals in the following order: Introduction, Activities, Objectives, Evaluation Criteria and Contents (IAOEC) (Table 5). This sequence together with the aforementioned statements appear to indicate that the incorporation of misconceptions seemed to initially arise in the *Introduction* as a list of the frequent mistakes. Then, future teachers were able to select, adapt or develop *Activities*, which considered children's ideas. Subsequently, they specified their educational *Objectives* in their proposals. Finally, they were able to add these topics to the sections of *Evaluation Criteria* and *Contents*. Remarkably, this sequence suggests that future teachers thought of evaluating these contents before incorporating them as educational contents.

Our study has some clear limitations that could be easily overcome in future studies. The absence of a control group that had not been taught neuroscience content weakens any general conclusion drawn from the results. However, this study proposes an innovative integration of neuroscience knowledge in the training of pre-service teachers. In this sense, our study is comparable with other studies that challenge future teachers with real situations and show how they develop their PCK [25,11]. Future studies should study in more detail the benefits of integrating the neuroscience of learning and perception in training future teachers.

5. Conclusions

In this initial training course of Didactics of Physics, we have observed the effect of integrating neuroscience contents in the initial training of future teachers. The inclusion of neuroscience content appeared to have a double impact. Firstly, there was an overall increase of the application of alternative conceptions in their proposals (see Table 5). Secondly, a reflection on some aspects related to PCK was stimulated. As showed in the quotes, future teachers discussed: what should a teacher know, what should them include in educational proposals and how should them outline their teaching.

In other words, understanding the physiological limitation encouraged them to reconsider what to teach and how to teach it.

Nevertheless, the neuroscience content was not considered teaching content to be taught to secondary school pupils. This topic was essentially used as a guide for teachers. Pre-service teachers appeared to feel more confident, because they considered that facing the neurophysiology of the thermosensory system is a complex and challenging task. In particular, they lowered their expectations and became less frustrated. They understood that it is not expected to quickly modify pupils' alternative conceptions.

6. References

[1] Friedrichsen, P.J, Van Driel, J.H. and Abell, S.K. 2011. Taking a closer look at science teaching orientations. *Sci. Educ.,* **95** 2, 358-76.
[2] Haefner, L. A. & Zembal-Saul, C. 2004. Learning by doing? Prospective elementary teachers' developing understandings of scientific inquiry and science teaching and learning. *Int. J. Sci. Educ.*, **26** 13, 1653-74.
[3] Magnusson, S., Krajcik, J., & Borko, H. 1999. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education*. (Dordrecht: Kluwer Academic). 95–132.
[4] Davis, E. A. 2004. Knowledge Integration in Science Teaching: Analysing Teachers' Knowledge Development. *Res. Sci. Educ.*, **34** 1, 21-53.
[5] Bryan, L.A. 2013. In B.J. Fraser, K. Tobin and C.J. McRobbie (eds.). *Second International Handbook of Science Education.* (Kluwer Academic Publishers). 477-95.
[6] Yerrick, R., Parker, H. & Nugent, J. 1997. Struggling to promote deeply rooted change: The "filtering effect" of teachers' beliefs on understanding transformational views of teaching science. *Sci. Educ.,* **81** 2, 137-57.
[7] Skamp, K. & Mueller, A. 2001. A longitudinal study of the influences of primary and secondary school, university and practicum on student teachers' images of effective primary science practice. *Int. J. Sci. Educ.*, **23** 3, 227-45.
[8] Rivero, A.; Azcárate, P.; Porlán, R.; Martín del Pozo, R. & Harres, J. 2011. The progression of prospective primary teachers' conceptions of the methodology of teaching. *Res. Sci. Educ.*, **41**, 739-69.
[9] Crawford, B. and D. Capps. 2018. In J. Dori, Z. Mevarech, and D. Baker (Eds.), *Cognition, metacognition, and culture in STEM education.* (New York: Springer) 9-32.
[10] Shulman, L.S. 1986. Those who understand: Knowledge growth in teaching. *Educ. Res.,* **15**, 4–14.
[11] Nilsson, P. 2008. Teaching for understanding: The complex nature of pedagogical content knowledge in pre-service education. *Int. J. Sci. Educ.*, **30** 10, 1281-99.
[12] Van Driel, J. H., Verloop, N., & de Vos, W. 1998. Developing science teachers' pedagogical content knowledge.*J. Res. Sci. Teach.*, **35** 6, 673-95.
[13] Yip, D. Y. 2001. Promoting the development of a conceptual change model of science instruction in prospective secondary biology teachers. *Int. J. Sci. Educ.*, **23** 7, 755-70.
[14] Driver, R. 1985 *Children's ideas in science.* (UK: McGraw-Hill Education).
[15] Vosniadou, S. 1994. Capturing and modeling the process of conceptual change. *Learn. Instr.*, **4** 1, 45-69.
[16] Wenning, C. J. 2008. Dealing more effectively with alternative conceptions in science. *J. Phys. Tchr. Educ.,* **5** 1, 11-19.
[17] Ezquerra-Romano, I. and Ezquerra, A. 2017. Highway to thermosensation: a traced review, from the proteins to the brain. *Rev. Neurosci.,* **28** 1, 45–57.
[18] Ezquerra, A. and Ezquerra-Romano, I. 2018. From Thermosensation to the Concepts of Heat and Temperature: A Possible Neuroscientific Component. *Eurasia J. Math. Sci. Technol. Educ.,* 2018, **14** 12, 1305-8223.
[19] Abell, S. K., Appleton, K. y Hanuscin, D. 2010 (NY: Routledge-Taylor y Francis).

[20] Pilitsis, V., and Duncan, R.G. 2012. Changes in Belief Orientations of Preservice Teachers and Their Relation to Inquiry Activities. *J. Sci. Teacher. Educ.*, **23** 8**,** 909-36.

[21] Lemberger, J. Hewson, P. and Park, H. 1999. Relationships between prospective secondary teachers' classroom practice and their conceptions of biology and of teaching science. *Sci. Educ.*, **83**, 347-71.

[22] Duschl, R., S. Maeng and A. Sezen. 2011. Learning progressions and teaching sequences: a review and analysis. *Stud. Sci. Educ.,* **47** 2, 123–82.

[23] Schneider, M. R. y Plasman, K. 2011. Science teacher learning progressions: a review of science teachers' pedagogical content knowledge development. *Rev. Educ. Res.*, **81** 4, pp. 530-65.

[24] Abell, S. K. 2007. In S. K. Abell y N. Lederman (eds.), *Handbook of Research on Science Education.* (New Jersey: Lawrence Erlbaum Associates).

[25] Jong, O. D., Van Driel, J. H., & Verloop, N. 2005. Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *J. Res. Sci. Teach.*, ***42*** 8, 947-64.