



Research article

Improving the self-regulation in prospective science teachers: the case of the calculus of the period of a simple pendulum



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ABSTRACT

This paper addresses the need to perform laboratory activities in secondary education science subjects, and what prospective science teachers feel while they themselves are doing these activities in their initial training. A laboratory activity based on the calculation of the oscillation period of a simple pendulum was done with 12 prospective teachers at the University of Extremadura, who were specializing in Biology/Geology, Physics/Chemistry, and Mathematics. When they had finished the activity they filled out a questionnaire about the difficulty, reasoning, capability, and emotions they had experienced in each of the stages needed to resolve the problem. The results showed how, as they go developing the stages of scientific methods, prospective teachers improve their reasoning and capability, and change negative emotions into positive ones, ending with being able to solve the problem on their own.

1. Introduction

Research into the science education has mainly dealt with the cognitive factors of teaching and learning different science subjects, while neglecting the affective and emotional domain. The transmission of science as a set of finished and indisputable truths has alienated it from the pupils, and moved it far away from the actual emotions that it aroused at the historical moment of the construction of knowledge (Mellado et al., 2014). However, there are also reasons to believe that, in the history of science, "conceptual change is emotional as well as cognitive" (Thagard, 2008: 385).

Popper (1978) established the theory of the three worlds: the first world is the physical world; the second world includes the processes of learning and construction of knowledge, both individually and collectively; and the third world includes the products of the human mind, among which scientific knowledge is found, structured in theories. For Manassero and Vazquez (2019) the epistemological reflection on the three worlds constitutes the fourth world. In science teachings has prevailed an abusive orientation transmissive (the third world), and the social, cultural, historical or affective, belonging to second world, have been excluded. For Popper (1978) the second world is "the mental or

psychological world, the world of our feelings of pain and of pleasure, of our thoughts, of our decisions, of our perceptions and our observations; in other words, the world of mental or psychological states or processes, or of subjective experiences" (p. 143).

The study of the emotions was dealt with by Darwin (1872) in his book "The Expression of the Emotions in Man and Animals" which already reflected on emotions as being part of our evolutionary structure, fulfilling a function of adaptation to our surroundings, and having been important in the survival of our own species.

In recent years, there has been a growth in research on emotions in science education, and the theme is present in current educational research agendas (Abrahams, 2009; Bellocchi et al., 2013; Dos Santos and Mortimer, 2003; Ritchie et al., 2011; Schutz and Zembylas, 2011; Zembylas, 2007). Emotions are a central part of action and decision-making in science education, and function as a social glue that interconnects individual and collective interests and actions (Tobin, 2012). Constructivism also addresses emotions, and the results show that teachers who ignore the affective aspects of learning may limit the conceptual changes in their pupils (Chiang and Liu, 2014; Duit and Treagust, 2012). Rosiek and Beghetto (2011) noted that teachers rarely recognize dichotomies between the cognitive and the affective, but instead integrate the two

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aspects into their pupils' learning process.

There has also been an increase in research on teachers' emotions, although, as acknowledged by [Uitto et al. \(2015\)](#), more research is needed on this aspect in the teaching of specific content. Many authors consider that the emotions about the teaching and learning of the different subjects should be part of a teacher's pedagogical content knowledge (PCK) ([Garritz, 2010](#); [Kind, 2009](#); [Melo et al., 2017](#); [Padilla and van Driel, 2012](#); [Park and Oliver, 2008](#); [Zembylas, 2007](#)). Indeed, [Shulman \(2012\)](#) noted that ignoring the affective side was one of the weaknesses of the initial formulations of PCK, and argues that emotions should be included.

Initial teacher training is constituted as a space in which both cognitive and affective aspects must be considered, since the process of learning to teach science is both cognitive and emotional ([Bellocchi et al., 2014](#)), and emotional regulation is one of its functional components ([Oosterheert and Vermunt, 2001](#)). [Torrecilla, Martínez, Olmos and Rodríguez \(2014\)](#) agreed with this in noting that the secondary teacher must be capable of working transversally, motivating competencies related to values, beliefs, attitudes, and procedures.

The ongoing need to improve the quality of teaching and learning mainly entails teachers adapting their professional skills so as to be able to teach in the different educational posts they may occupy. This is difficult since the demands of society towards these emerging needs are increasingly complex ([Gutiérrez, 2011](#)). It is necessary to train emotionally competent teachers who can diagnose and self-regulate their emotions, applying intervention programs that include both the cognitive and the affective ([Borrachero et al., 2017](#); [Efklides, 2009](#); [Koballa and Glynn, 2007](#)).

The first experiences of teaching during teaching practices are emotionally very strong, and negative emotions can promote behavioural strategies that are aimed towards control and survival. The practicum period thus becomes the ideal time to carry out these activities, as it is in these first teaching experiences when teaching routines and strategies are most established, consolidating beliefs, attitudes, and emotions which will be difficult to modify later ([Frenzel et al., 2011](#)).

Prospective teachers begin their professional training at a time when their experiences as pupils are still very recent, and they have beliefs that influence their professional knowledge ([Désautels et al., 1993](#); [Evans and Fisher, 2000](#); [Pontes and Poyato, 2016](#)). These beliefs are based on their experiences themselves as pupils, including explicit conceptual, procedural, and attitudinal knowledge and characteristics of the curriculum. There are also other implicit aspects, such as the memory of their teachers, the social climate in class, and emotions which these experiences generated ([Bonil and Márquez, 2011](#)).

In analyses of the memory of prospective primary ([Brígido, Couso, Gutiérrez & Mellado, 2013b](#)) and secondary teachers ([Borrachero et al., 2017](#)), the results show that these prospective teachers have an emotionally positive memory of science subjects when they were primary pupils. However, in secondary, the memory of their emotions depends on the content they were learning, being more positive towards Biology and Geology than towards Physics and Chemistry ([Brígido et al., 2013b](#); [Costillo et al., 2013](#)).

The emotions they express when teaching science subjects correspond to those they felt as pupils of these subjects in secondary education. Prospective primary teachers show positive emotions towards teaching Biology and Geology and negative ones towards teaching Physics and Chemistry ([Brígido et al., 2013b](#)). Prospective secondary teachers show positive emotions towards the teaching of the subjects that correspond to their speciality and negative ones to the others, with two exceptions: Biology, towards which all the participants had positive emotions, and Physics, in which even prospective Physics and Chemistry teachers have almost the same amount of positive and negative emotions, with more positive emotions for this subject being detected in men than in women ([Borrachero et al., 2014](#)). [Ritchie et al. \(2011\)](#), in a study of a novice science teacher, noted that positive emotions are related to the achievement of positive expectations and the failure of the negative ones,

while negative emotions are related to the failure to achieve positive expectations.

One worrying result is the finding of negative emotions felt towards Physics since, as [Laukenmann et al. \(2003\)](#) noted, success in learning Physics is linked to the existence of positive emotions such as joy and interest. The decline in demand for science studies in many countries ([Rocard et al., 2007](#)) may be related to the emotionally adverse context in which scientific learning takes place, centred on the abstract transmission of concepts and removed from the positive emotions of scientific activities.

[Damasio \(2010\)](#) pointed out that what causes negative emotions can only be countered by generating even stronger positive emotions. This means that it is necessary to foster positive emotions towards the teaching and learning of the sciences so as to be able to counteract the negative emotions that may have been generated during the years at school. [Izquierdo \(2013\)](#) believes that doing science is exciting because it is the expression of the desire to know and understand the world we live in. The challenge is to change, through creative and exciting scientific activities, the negative emotions to positive ones such as pleasure, pride, satisfaction, joy, trust, and many others that throughout history have made scientific activities an adventure of the mind, and that have contributed decisively to the understanding of nature and the progress of mankind ([Mellado et al., 2014](#)).

Research on the science education has resulted in the elaboration of some science teacher training programs aimed at developing meta-cognitive capabilities ([Brígido et al., 2014](#); [Copello and Sanmartí, 2001](#); [García and Orozco, 2008](#); [Gunstone and Northfield, 1994](#); [White and Mitchell, 1994](#)). These skills favour the recognition of possible causes of difficulties or problems when teaching, and also facilitate the self-regulation of changes in affective factors within the process of teaching science and the development of new activities, materials, and education proposals ([Powell and Anderson, 2002](#); [Sassi et al., 2005](#)).

The intervention program we are implementing at the University of Extremadura is being carried out with interdisciplinary teams, and with both general activities of emotional coping and control, and specific activities about learning and teaching sciences ([Borrachero et al., 2017](#)). The challenge of the program is not only to train emotionally competent teachers who are able to diagnose and self-regulate their emotions when teaching and learning sciences, but also to equip them with tools which will help build an effective system of self-regulation and allow their self-training throughout their professional career ([Sanmartí, 2001](#)).

This paper analyses how, through an experience about the pendulum which combines the resolution of open scientific problems with practical tasks, negative emotions can be transformed into positive ones. [Matthews \(2000\)](#) pointed to the need to make the affective dimension explicit in the study of the pendulum.

The choice of this activity was based on the importance that the pendulum has had in the development of Western science and culture. Galileo, Huygens, and Newton studied the pendulum, and it was crucial in the development of mechanics, in determining the acceleration of gravity, in the manufacture of watches, and in navigation ([Gauld, 2004](#); [Matthews, 2000](#); [Matthews et al., 2004](#)).

[Koliopoulos and Constantinou \(2005\)](#) argued that school activities about the pendulum could integrate conceptual, methodological, and cultural aspects, and proposed as an activity the calculation of which variables the oscillation period of the simple pendulum depends on. [Zachos \(2004\)](#) pointed out that, with activities about the simple pendulum, pupils can acquire the scientific skills necessary to inquire into and discover the laws of nature. [Matthews \(1989, 2001\)](#) emphasizes that studies about the pendulum can illustrate the important role that the history and philosophy of science has in the science education.

From the very first works of [Lederman et al. \(1992\)](#) to the most current ones ([Lederman, 2007](#)), we know that: a) most of the elementary and secondary teachers possessed inadequate points of view on the nature of science; b) teachers' conceptions on the nature of science do not necessarily influence their classroom practice; and c) conceptions on

nature of science are best learned through explicit reflection. The reflection on the activity of the simple pendulum makes it possible to compare the logic of justification with that of discovery, as well as to make explicit different conceptions about the nature of science.

The formative possibilities of the simple pendulum in science teaching have been recognized since the experiences of [Inhelder and Piaget \(1958\)](#). These experiences showed it to be an accessible activity that includes different components of the scientific method and can foster both cognitive and affective factors. The determination of the variables which the period of the pendulum depends on has been used as a scientific learning activity by [Galili and Sela \(2004\)](#), [Kanari and Millar \(2004\)](#), [Martínez-Pérez \(2015\)](#), and [Zachos et al. \(2000\)](#).

The calculation of the different variables that influence the oscillation period of the simple pendulum presents itself as an emotional and cognitive intervention activity that combines practical laboratory activities with problem solving – two traditionally separate activities, although together they have a huge potential for education. [Gil et al. \(1999\)](#) advocate for a form of learning science that integrates problem solving and practical work, since both require shared activities to be carried out of inquiry or small investigations in an environment of social collaboration. It is important that prospective secondary teachers value their skill and the emotions generated by laboratory activities ([Randi, 2004](#)) because in this way they will be able to better understand their pupils' emotions, empathizing with them and creating a positive climate towards science learning.

Group activities enhance communication and reasoned discussion, two important aspects of scientific activity, allowing the participants to construct shared meanings. In practical inquiry activities, real discussions take place which stimulate the role of language in the social construction of knowledge ([Jiménez-Aleixandre and Díaz de Bustamante, 2003](#)). [Varela and Martínez \(1997\)](#) suggested that the use of these strategies would improve pupils' learning, although they also pointed to the need to analyse the obstacles that might be encountered when carrying out inquiry activities or small investigations.

The activity of the calculation of the simple pendulum period was chosen because it includes different steps of the scientific methodology. In addition, it is an activity of high cognitive level and very significant in the history of science. Moreover, it does not require any specific material to make it, you can use everyday materials. To conclude, inform that the end is not the activity itself, but the results of the process of construction of scientific knowledge.

Our intention with this activity is to make prospective secondary science teachers aware of the difficulty, reasoning, capability, and emotions that laboratory activities can generate in their future pupils, and to be capable of self-regulation so as to achieve a satisfactory result. To this end, we set ourselves a series of specific objectives:

1. To determine and make the participants aware of the difficulty, level of reasoning, and capability they had in the seven stages of the simple pendulum activity: initiation, formulation of hypotheses, experimentation, representation of results, analysis of results, search for regularities, and application.
2. To determine and make the participants aware of their emotions in each of the seven stages of the simple pendulum activity: initiation, formulation of hypotheses, experimentation, representation of results, analysis of results, search for regularities, and application.
3. To analyse and foster the self-regulation of the negative emotions that arise in the simple pendulum activity.
4. To foster reasoning and the capacity to solve problems, overcoming the difficulties the participants may encounter.

2. Methods

2.1. Sample

The sample comprised a total of 12 prospective science teachers

taking the Master's Degree of Secondary Education Teacher Training (Spanish acronym, MUFPE) at the University of Extremadura in the academic year 2010/2011. This master's degree is offered in three science specialities: Biology/Geology, Physics/Chemistry, and Mathematics. Students' participation was voluntary. Before starting the experiment, all the instruments and protocols to collect data were approved by the university bioethics committee. The participation in this study was totally voluntary and no personal information was recorded for any participants. Students were informed that they had complete freedom to withdraw without consequences and, they filled out and signed the consent form. Also, they were informed that the study would attempt to publish without disclosing any personal data.

To guarantee the quality of the activity and to avoid having very large groups that would be difficult to control throughout the study, we decided that the ideal would be to have three students for each speciality. However, as one sees in [Table 1](#), we actually chose a greater number from the Biology/Geology speciality. This was because most of the students enrolled in the MUFPE were graduates of biology-related degrees, so that we formed two groups for this speciality.

[Table 1](#) gives the distribution of the sample by gender, age, and bachelor's degree. To guarantee the anonymity of the participants, they were each assigned a number. There were 7 women and 5 men, of ages between 23 and 29.

2.2. Procedures for collecting and analysing the data

As indicated above, the proposed activity consisted in calculating the variables on which the oscillation period of a simple pendulum depends. Here the participants leave their role of prospective teachers to once more become science students.

The activity began by dividing the participants into 4 groups, each consisting of 3 participants: 2 from Biology/Geology, 1 from Physics/Chemistry, and 1 from Mathematics. In this way, equity of the groups was ensured. We believe that scientific activity is a social and collective activity, where the confrontation of ideas and argumentation play a very important role. In addition, collaboration between the different members of the group favours peer learning.

The session was carried out in the Laboratory of Physics Education in the Faculty of Education at the University of Extremadura, which is equipped with all the means they might need to perform the practical activity. To set up the problem that they had to solve by themselves, a small steel ball was attached to a thread and made to oscillate. Then the following question was asked: "What variables does the oscillation period of the pendulum depend on?"

Each group had at their disposal different items with distinct shapes and masses, as well as skeins of thread to hang them on. They were told that all the laboratory's materials were at their disposal and that, without further guidance, they had to reach the final solution. With the participants' consent, the activity was recorded on video which they could later review, to see how they had acted and reflect upon it.

Table 1

Distribution of the sample by gender, age, and bachelor's degree.

Participants	Gender	Age	Graduate	
Biology/Geology	Student 1	Male	29	Biology
	Student 2	Male	29	Biology
	Student 3	Female	28	Biology
	Student 4	Female	27	Biology
	Student 5	Male	27	Food Science and Technology
Physics/Chemistry	Student 6	Female	24	Biology
	Student 7	Male	28	Physics
	Student 8	Female	24	Chemistry
Mathematics	Student 9	Female	23	Chemistry
	Student 10	Male	24	Mathematics
	Student 11	Female	23	Mathematics
	Student 12	Female	23	Mathematics

To evaluate the activity, a questionnaire was prepared (Annex) that dealt with the degree of difficulty of the experience, the group reasoning for the decisions taken, and the belief in one's own capability to solve the problem or self-efficacy. All the items were measured on a 10-point Likert scale, in which 1 was the lowest and 10 the highest.

It should be noted that self-efficacy is closely related to self-regulation, and is a powerful predictor of the participants' achievement. Borrachero, Davila and Costillo (2016) note that their subjects who thought they were capable of learning certain content had more positive emotions towards that content, but when they felt incapable they experienced more negative emotions. This is especially important for the contents of Physics and Chemistry which cause more negative emotions and are most influenced by self-efficacy (Brígido, Borrachero, Bermejo & Mellado, 2013a).

There are many taxonomies for emotions, but in focusing on how emotions affect behaviour one can classify them into two types: positive and negative. Positive emotions produce pleasant feelings, with short temporal duration, and negative emotions produce unpleasant feelings as well as mobilizing many resources with which to be able to cope with them (Fernández-Abascal et al., 2001). In the questionnaire, the emotions that arose were openly consigned to one of these types.

To calculate the pendulum's oscillation period, the participants went through seven different stages: initiation, formulation of hypotheses, experimentation, representation of results, analysis of results, search for regularities, and application. The activity lasted approximately 3 h, and after having completed the activity the participants completed the questionnaire.

Regarding the roles of the researchers present in the activity, they acted as facilitators and guides, but in no case showing the solutions to the problems put by each group. Crujeiras-Pérez (2017) analysed support strategies during inquiry activities, such as: initial motivation, problematization of the task, formulation of relevant questions, fostering discussion and evidence-based argument, hints, formulation of doubts and contradictions, etc.

3. Results and discussion

3.1. Initiation

To begin, each group is positioned in a corner of the laboratory. They start by sharing the roles among themselves, although during the activity the actions emerge spontaneously. They have to identify and set out the problem to be solved, and begin with a brainstorming of ideas. At this stage, each group decided on how to set up the experiment.

The participants' self-assessment through the questionnaire indicates that at this stage they had more difficulty in identifying the problem than

in actually setting it out, despite feeling more capable of doing the former than the latter. Setting the problem out led them to do more reasoning than just identifying it (Fig. 1).

The emotions experienced in this first contact with the problem (Fig. 2) were mostly negative (uncertainty, nervousness, worry, stress, and frustration), although it is also worth noting the positive emotion of curiosity, a fundamental emotion in scientific activities. Discussion also means valuing negative emotions as being something natural during the process: uncertainty because the results are not known, worry about doing well, nervousness in doing an activity they are not accustomed to, etc. In an analysis with the model of Diaz and Flores (2001), there are both positive and negative emotions that stimulate action and others that lead to the activity being abandoned.

3.2. Formulation of a hypothesis

In this second part of the activity, the participants began to think about the variables that could influence the oscillation period of a simple pendulum. The shape of the object, mass, length of the thread, force with which it is launched, height from which it is dropped, etc. They do not formulate hypotheses as such, but begin to postulate ideas that are then discussed among themselves.

Fig. 3 shows that the self-evaluation at this stage indicates that they felt quite capable of doing the activity, and that it required a high degree of reasoning. The difficulty they found at this stage of the experience was medium.

Fig. 4 shows that the search for variables caused mostly negative emotions in the participants, although some also experienced positive emotions. The relation of this exercise with their previous ideas caused a smaller number of negative emotions coexisting with positive ones (curiosity, confidence, and enthusiasm).

3.3. Experimentation

After formulating the possible variables involved in the oscillation of the pendulum, the groups began to experiment with the objects. They carried out several measurements of the oscillation, with different weights and shapes, different lengths of thread and heights, giving a greater or lesser push to the launch. The person in charge of moving the pendulum was chosen by the group because of having the steadiest pulse. The different groups agreed with the work of Zachos (2004) who pointed to three possible variables on which the oscillation period of the pendulum might depend: mass, length of the thread, and height from which it is launched.

For Inhelder and Piaget (1958), the separation of variables is reached at the stage of abstract operations. The groups did not have any problem

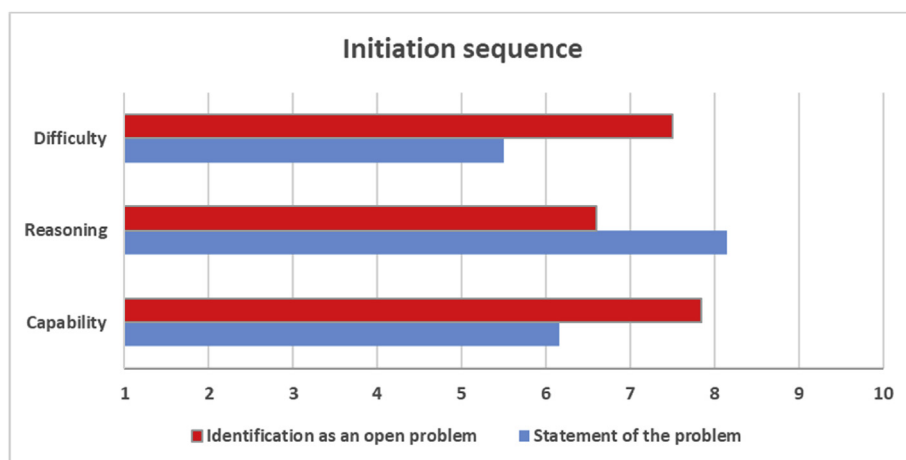


Fig. 1. Mean scores in the evaluation of the initiation stage.

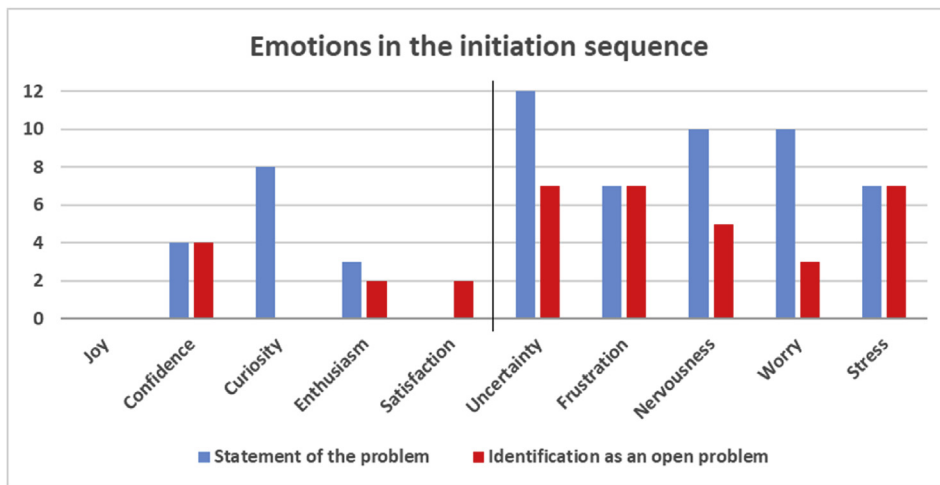


Fig. 2. Frequencies of the emotions experienced in the initiation stage.

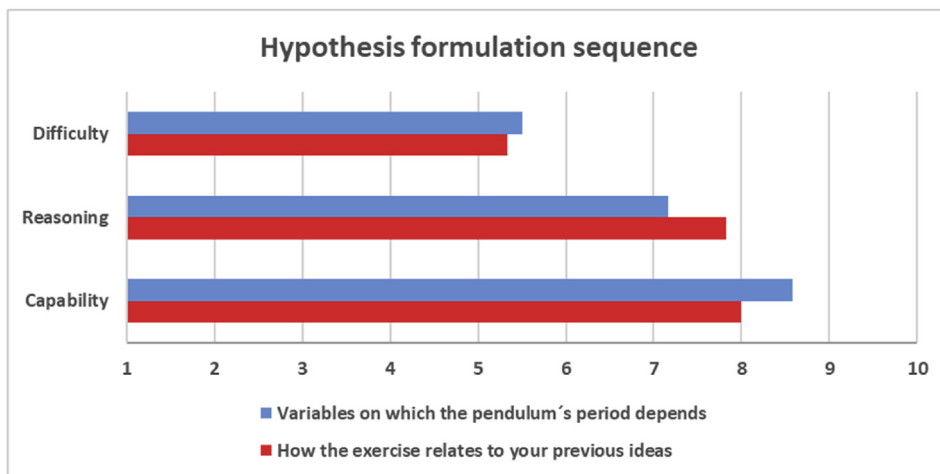


Fig. 3. Mean scores in the evaluation of the formulation of hypotheses stage.

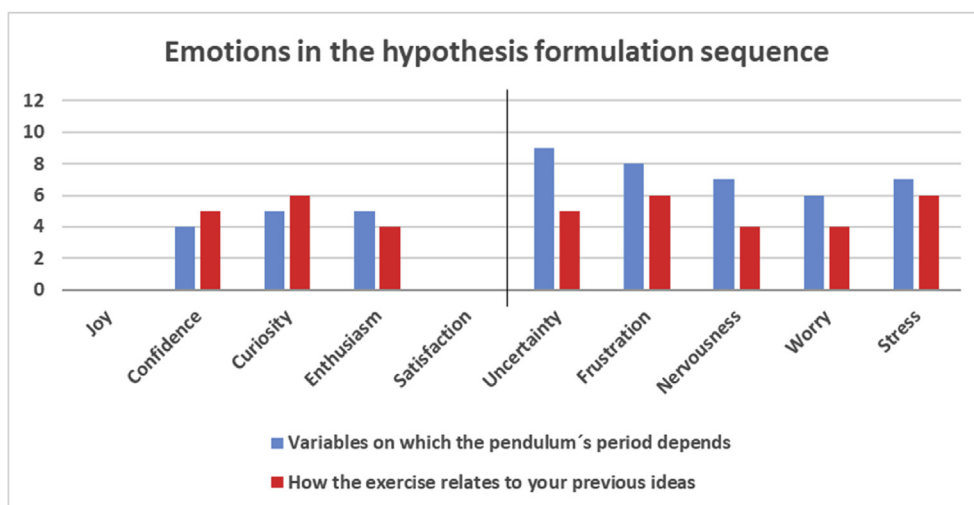


Fig. 4. Frequencies of the emotions experienced in the formulation of hypotheses stage.

with this aspect, and, to determine the dependency of a variable, they took measurements with all the other possible variables fixed. Kanari and Millar (2004) argued for the use of the simple pendulum to give pupils

the capability of analysing variable dependency, since in everyday life they will have to make decisions regarding this aspect.

The students measured the oscillation of the pendulum with a

chronometer, which is very difficult. They realized for themselves that the best way was to measure the total time of several oscillations and then to divide it by the number of times that the pendulum had given a complete oscillation. Zachos (2004) recognized that this activity allows for discussion of the errors in the measurements and how to reduce them.

The repetition of the different trials led to discussion of the results they had obtained. In this way, they found that the oscillation does not depend on the impulse with which it was launched, the height from which it was thrown, or the mass of the object, but on the length of the thread to which it is attached.

At this stage it becomes clear that there are different ways of solving problems: most of the groups began to measure directly (quantitative procedures), however some qualitative procedures were also tried, like hanging two parallel pendula with the same length but different masses, and observing that the oscillation is the same, which thereby discarded mass without the need to make any other measurements.

All the groups thought that the oscillation period also depended on the mass, and when they found that it did not this caused them surprise and disbelief, and they repeated some of the measurements. The belief in the dependency on mass is a deeply rooted alternative idea that can only be restructured from one's own data.

All the groups reached the conclusion that the oscillation period of the pendulum only depended on the length of the thread. However they all took length as being exclusively that of the thread and not the distance to the centre of mass of the object. We presented them with doubts and contradictions at this stage, asking them to make measurements with the same length of thread, but sometimes hanging the thread at the end of a rod and at other times from its centre, or with several objects hanging in a cluster or in a line.

This represented a contradiction for the students, since they realized that the oscillation period is greater when the rod is hung from its end, and shorter when hung from its centre. After some discussion and argumentation, they came to the conclusion that the length must be taken from the centre of mass of the hanging object. This is one of the most problematic points in the experience in that the teacher's guidance is required, and which differentiates an experience with an autonomous discovery model from one with a guided model. There were also discussions about some variables such as air resistance or how the mass is launched which had not been taken into account in the activity because their influence is negligible in this kind of experiment.

The participants' self-evaluation showed that they had less difficulty in separating the variables, and felt more qualified and used a greater degree of reasoning in this aspect of the activity. They did find greater difficulty in the centre-of-mass problem, in which they felt less qualified and they showed a lower level of reasoning ability (Fig. 5).

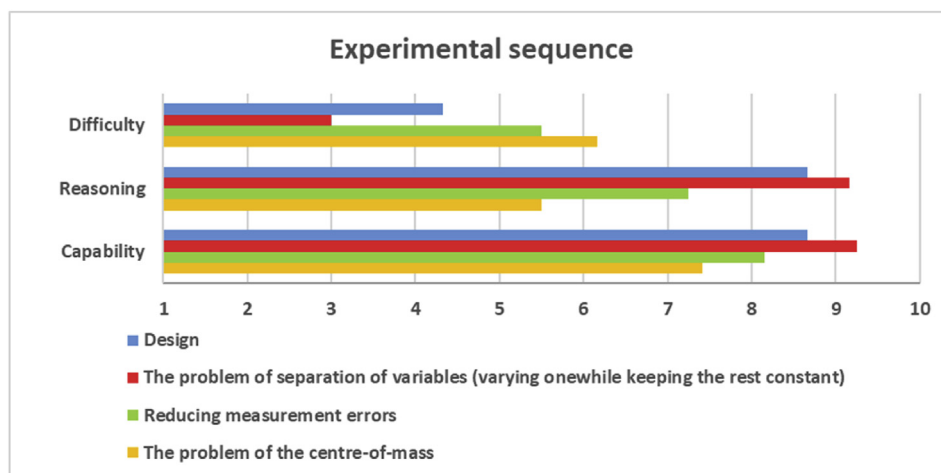


Fig. 5. Mean scores in the evaluation of the experimental stage.

The emotions experienced by the participants in this part of the activity were mostly negative, although some also experienced positive emotions such as curiosity, enthusiasm, confidence, and satisfaction (Fig. 6).

3.4. Representation of results

Once they had determined that the oscillation period depended on the length as measured from the centre of mass, they repeated the measurements over a wider range of lengths. Then they had to give meaning to what they had noted down, and to the conclusions they had reached, making tables and graphs with the data they had obtained (Fig. 7). They were also asked to calculate the oscillation of the pendulum with different lengths. In this and the following stages, the application of mathematics is highlighted as a very useful tool to help interpret and relate the data.

Fig. 8 shows that they also found this stage difficult. They felt less capable of using mathematical functions, and with these functions they used a lower degree of reasoning.

At this stage, the negative emotions have decreased markedly in comparison with the previous stages. There stand out the emotions of satisfaction and frustration (Fig. 9). However, it is particularly necessary to analyse frustration, as this can be a depressing and paralysing emotion, leading to the activity being abandoned. It must be noted that there appear positive and negative emotions in the process of any scientific activity, and it is necessary to know how to diagnose them and use the appropriate tools to deal with and overcome them.

3.5. Analysis of results

At this stage of the activity, they began to draw their own conclusions. First they analysed the graph T/L (in which T is the simple pendulum oscillation period and L is the length of the thread), relating it with what they had studied about mathematical functions during their academic life. Scientific inference of laws from data is a creative and genuinely scientific process, as most students are accustomed to the teacher giving them the correct solution; this was not the case in this experience. The first supposition they start from is that there is a linear relationship between the variables: $T/L = k$. However both the graph and the results for T/L reject this relationship.

Fig. 10 shows that this stage gives them less difficulty than the previous ones. They use more reasoning, and feel very capable of developing this sequence.

Here, all the emotions they experienced were positive, with satisfaction and confidence standing out (Fig. 11).

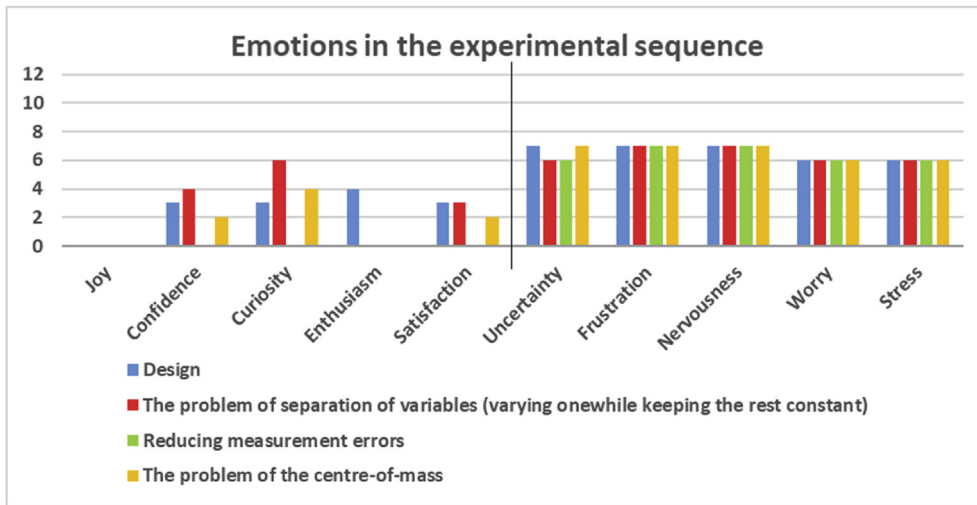


Fig. 6. Frequencies of the emotions experienced in the experimental stage.

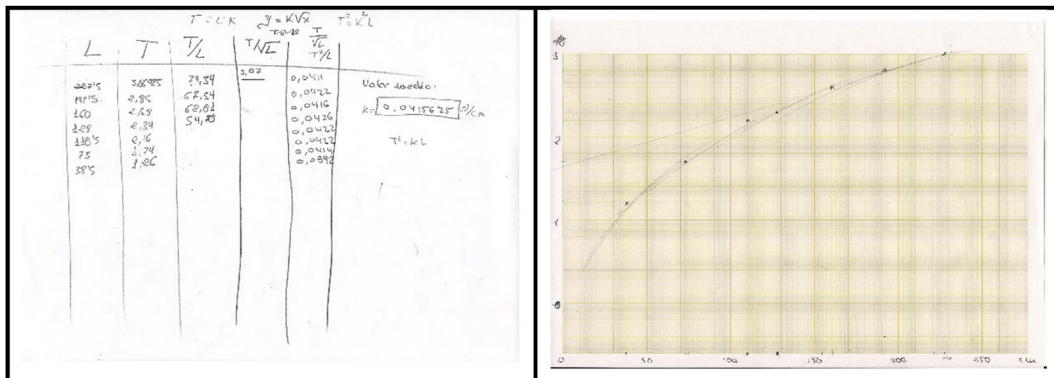


Fig. 7. Example of a group's table and graph about the oscillation of the pendulum.

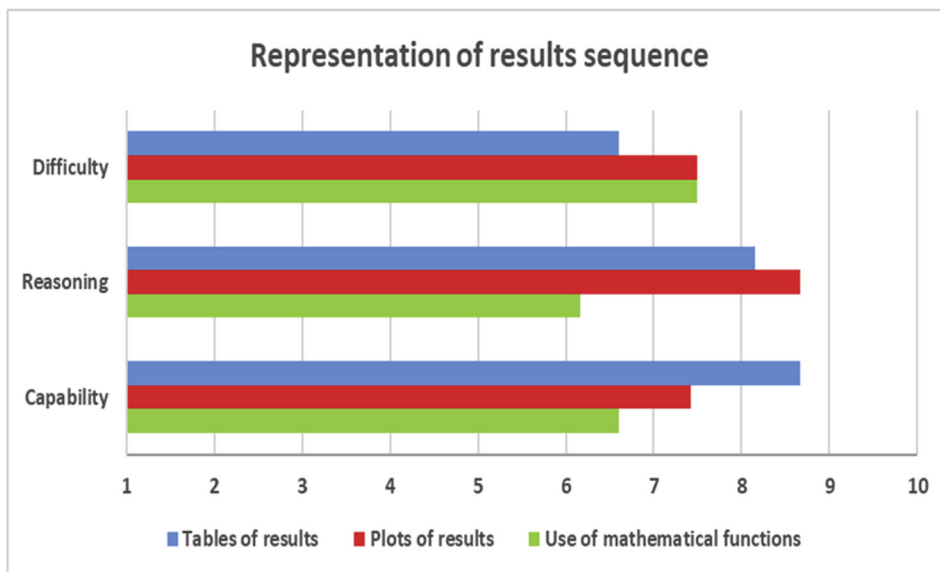


Fig. 8. Mean scores in the evaluation of the representation of results stage.

3.6. Search for regularities

Having discarded the linear relationship between the variables T and L , the participants continued to search for regularities. The graph seemed

to them to be a curve. They did not know how to express this, however. The teacher needed to keep encouraging them, and getting them to propose relationships between the two variables. Finally, after lengthy discussions, they proposed checking the L^2/T and T^2/L relationships.

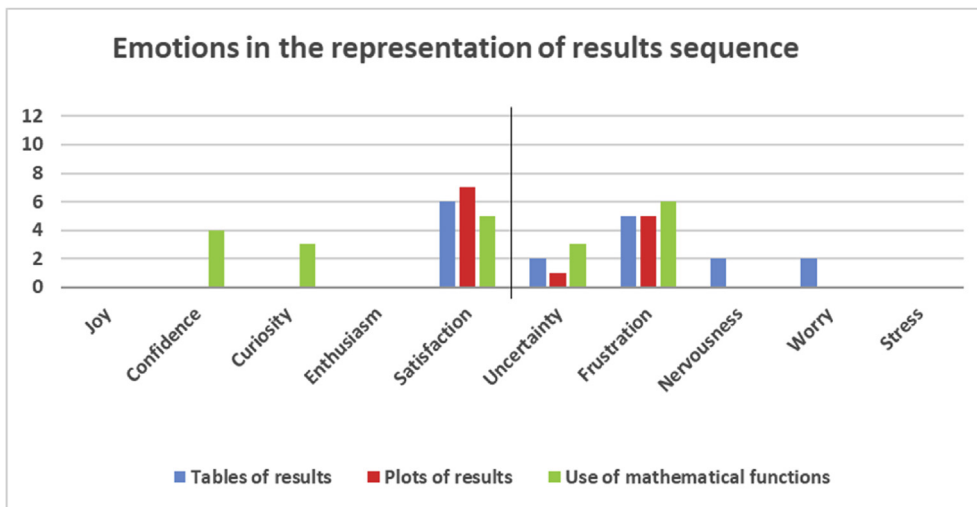


Fig. 9. Frequencies of the emotions experienced in the representation of results stage.

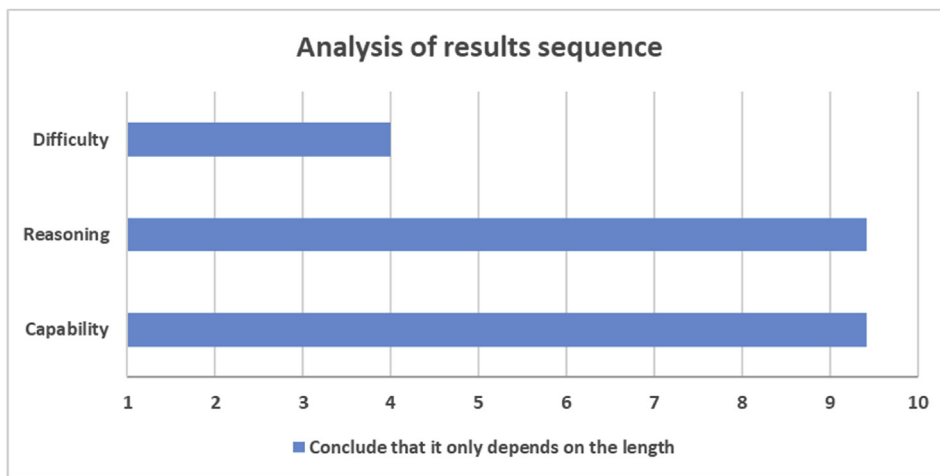


Fig. 10. Mean scores in the evaluation of the analysis of results stage.

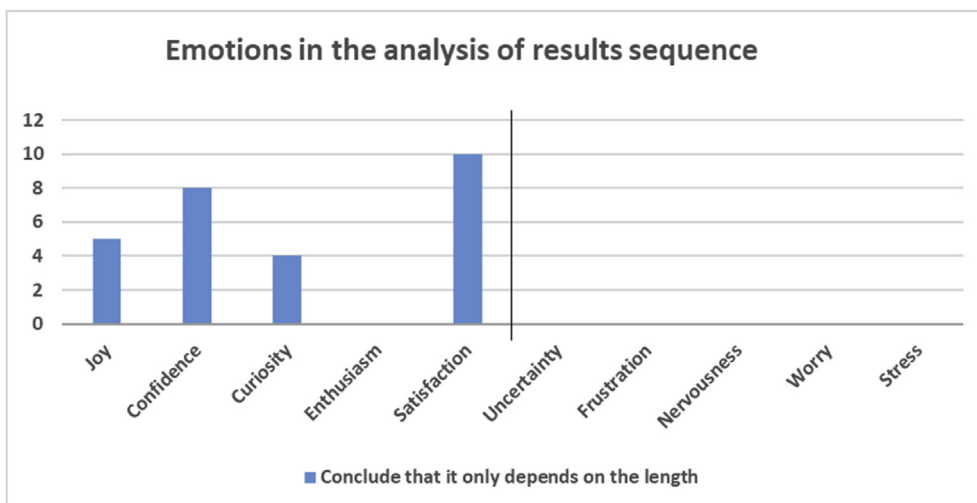


Fig. 11. Frequencies of the emotions experienced in the analysis of results stage.

They could see that the former is not constant, but found that the latter is. Each group calculated the constant by averaging their own data, reaching the conclusion that $T^2=k \cdot L$ (in which k is a constant). After several discussions and checks of the functions, the groups concluded that this corresponded to a parabola in mathematics. There was a discussion about the meaning of the constants in the physics formulas and the units in which they are expressed, as some groups had measured the length in metres and others in centimetres.

In the sequence of searching for regularities, they experienced less difficulty than in other stages, contrary to the results of Brígido (2014) with prospective primary teachers who had much less training in science and mathematics. For the sample of the present study, discarding the linear relationship seemed to be more difficult than the other sub-stages. In addition, the scientific inference caused them to use a greater degree of reasoning, although they felt less capable (Fig. 12).

The self-evaluation of their emotions at this stage of the experience was positive (satisfaction, curiosity, confidence), although it is noteworthy that fewer participants expressed emotions, unlike what had been the case in the other sequences (Fig. 13).

3.7. Application

Once they had reached this point at which they already knew what

the oscillation of the pendulum depended on, they were given Physics books with which to contrast their results. Some panicked a little at first, because equation $T = 2\pi \sqrt{L/g}$ that they found in the books (in which g is the acceleration due to gravity) is not the same as what they themselves had obtained. After a period of discussion, they understood that they had to transform it. Squaring both sides, they obtained the equation: $T^2=(4\pi^2/g) \cdot L$, which is the same form as what they had obtained $T^2 = k \cdot L$, with $(4\pi^2/g) = k$, as g is the acceleration due to gravity of the place of the experiment, and is a constant. They had successfully reached the end of the activity, collectively externalizing large amounts of positive emotions. Subsequently, with their own formulas, they managed to calculate the acceleration due to gravity in Badajoz (Spain).

The participants felt that the comparison with the literature and the application of the equation caused them little difficulty, with a high degree of reasoning, and in which they felt themselves very capable (Fig. 14).

The emotions experienced in this stage are clearly positive (satisfaction, joy, and confidence), with a total absence of negative emotions (Fig. 15).

Finally, the activity is compared with the traditional sequence of teaching the simple pendulum, in which the teacher first makes a demonstration on the blackboard of the mathematical formula, $T = 2\pi\sqrt{l/g}$, and then teacher proposes pencil and paper application

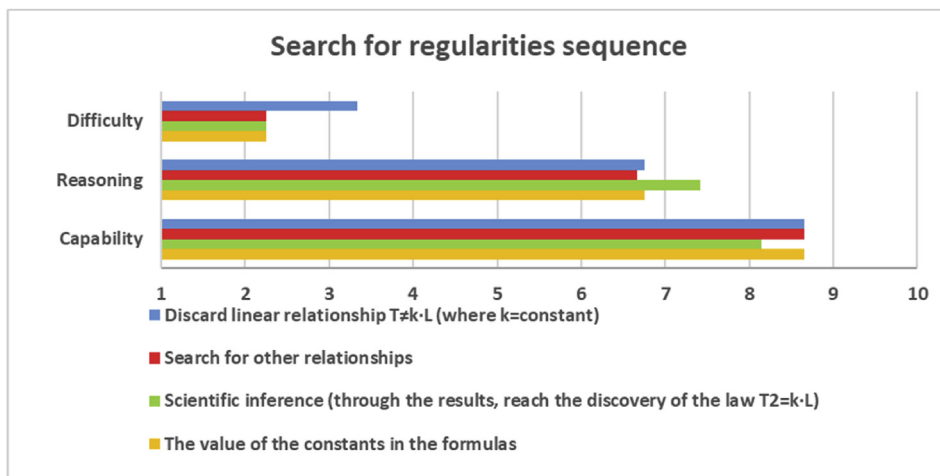


Fig. 12. Mean scores in the evaluation of the search for regularities stage.

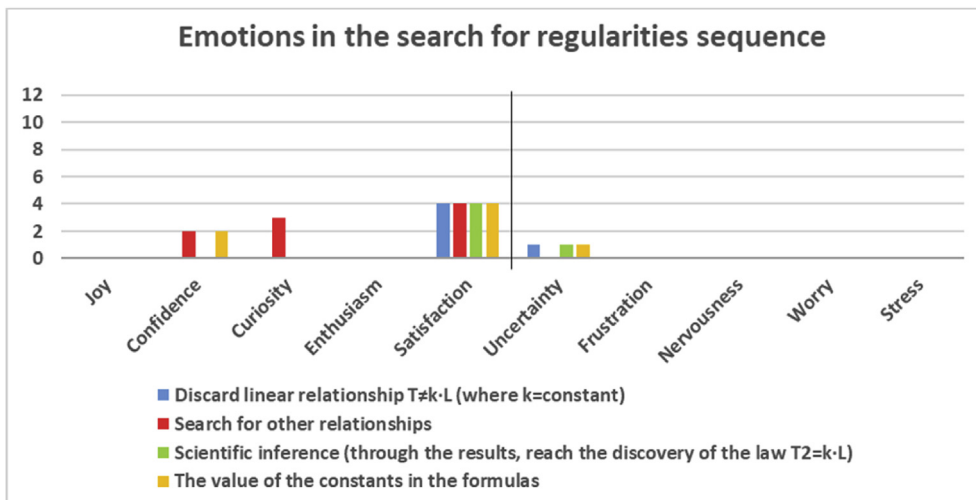


Fig. 13. Frequencies of the emotions experienced in the search for regularities stage.

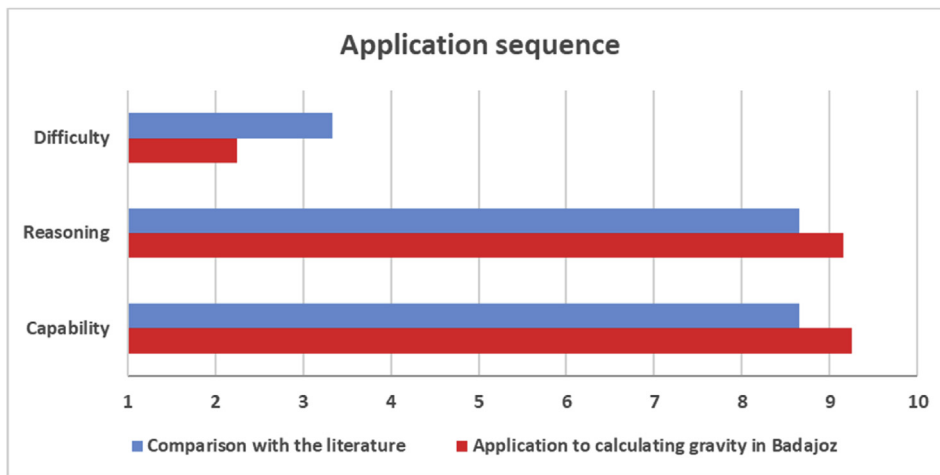


Fig. 14. Mean scores in the evaluation of the application stage.

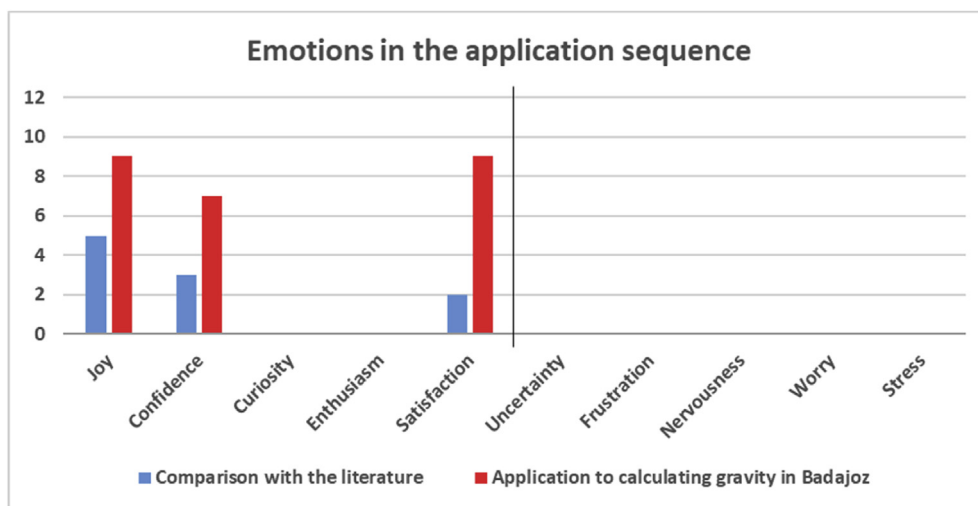


Fig. 15. Frequencies of the emotions experienced in the application stage.

problems of the formula. This discussion allows not only to compare the processes and learning difficulties of the two models, but also to discuss the nature of science, about the three worlds of Popper (1978) and to make explicit different conceptions about the nature of science.

4. Conclusions, implications and limitations

The conclusions of this study will be analysed according to the specific objectives set out at the beginning. The first objective was to make the participants aware of the difficulties that they might encounter during this experience, as well as the degree of reasoning and capability needed to reach a correct solution. Asking them to reach a solution without providing any data meant that they needed a high degree of capability and reasoning, and this was quite difficult for them. The study of each of the stages indicates that the difficulty level steadily decreased as they approached the solution, although in the stage of the actual application of their results the difficulty they experienced increased, especially when using mathematical functions and translating their results into graphs. Regarding the study on the degree of reasoning and capability, one can observe, in a general way, an inverse relationship. When they felt more capable, the degree of reasoning they used was less, and when they felt less capable, they used a greater degree of reasoning. This does not mean that the students who felt more capable did not reason, but that feeling efficacious when facing the problem they were

posed meant that there was less searching for strategies, and early success in the outcome. As the experience went on, the level of reasoning decreased, and the level of capability increased. The participants were aware of their own capability to cope with each of the laboratory activity stages since they looked for different self-regulating strategies to change what was hindering their self-efficacy to cope with the difficulties that arose. This is coherent with the ideas of Bandura (1997) who stated that people with high self-efficacy are capable of distinguishing complex exercises as being challenges to overcome rather than as threats to avoid, and indeed see them as challenges that require a greater commitment (Fernández et al., 1999). Instead, people unsure of their capabilities consider such cases to be more complicated than they actually are, which produces a certain despondency and an inability to resolve the problems (Pajares and Schunk, 2001).

The second objective was to determine, and to make the prospective teachers aware of, their emotions in each of the seven stages of the simple pendulum activity. At the beginning of the activity there was a notable amount of negative emotions, including uncertainty, nervousness, worry, and stress, although there was also curiosity. As the stages of the experiment progressed, the negative emotions at first persisted, but began to disappear when the students came to solving the problem by themselves, and positive ones, such as satisfaction, confidence, and joy, increased. During the course of the experiment, it was clear how the prospective teachers were aware of their frustration and stress, because

initially they did not know how to approach a possible solution, even when they had considerable knowledge about the subject. Satisfaction and joy upon reaching the solution were particularly notable. Thus, we consider that the development of the activity led the participants to reflect on their own affective components. This reflection is especially necessary because the literature indicates that when prospective teachers begin their practicums, they carry with them a set of beliefs, attitudes, and emotions that result from their memories of their own many years at school, either internalizing or rejecting the roles of the teachers they had at the different educational levels (Abell et al., 1998; Hewson and Hewson, 1989; Mellado et al., 2014.).

The third objective was to analyse and foster the self-regulation of the negative emotions that arise in laboratory activities. Although the prospective teachers were aware of their own negative emotions, they did not use self-regulation strategies to change them. They were caught up by the worry, nervousness, and stress they experienced at the very beginning of the activity. They remembered laboratory activities in their recent undergraduate education as being pleasurable, but in having to face these activities without any data they were aware of their psychological and pedagogical shortcomings (knowing how to self-regulate, understanding the key concepts, possible strategies, etc.). All of this caused them to have low self-efficacy.

In getting close to solving the problem, they experienced positive emotions. They had found self-regulation strategies that allowed them to move forward and not give up. Therefore, it could be said that with the pendulum experiment, which combines the resolution of open scientific problems with practical work, they managed to transform negative emotions into positive ones. Although negative emotions initially tend to disable self-regulatory behaviour, they can also motivate prospective teachers to change the conditions which generate those emotions (Melo et al., 2017; Pekrun, 1992). A certain degree of negative emotion helps them to leave the comfort zone, and stimulates their ability to find what it is that is not functioning in their teaching work. For Hugo (2008), emotional regulation in the process of learning to teach science is what happens when the prospective teacher manages not to let their emotions stop them from reaching their teaching goals, dealing with the conflicts that may arise along the way. But if negative emotions are experienced at high levels and are of a depressive type, the prospective teacher will block any possibility of self-regulation.

The fourth objective was to stimulate the reasoning and the capability to solve problems, overcoming any difficulties that may be found. The participants who had specialized in Biology/Geology were thought to be those who would find the activity most difficult. This was incorrect, however. Instead, it was the prospective Physics/Chemistry and Mathematics teachers who felt overwhelmed and frustrated because they did not know how to reach the solution, despite it being an activity close to their academic training. The Biology participants felt more relaxed, and contributed more strategies than the others towards reaching the solution. González, Mellado and Ruiz (2005) also found that, in this activity, the group dynamics was more constructive and collaborative in their Social Sciences participants than in those of the Natural Sciences, and that this enabled them to reach consensus on the results, despite their relatively less scientific knowledge. The groups with more Physics knowledge tried to apply their theoretical knowledge rather than investigating and asking questions. Perhaps the epistemological absolutism (Jiménez and Wamba, 2003) that these students received in their undergraduate training, which conceives of science as superior, true, and finished knowledge, closer to the logic of justification than to that of discovery, is still an obstacle to their solving open practical problems. As the activity went on, we observed that the difficulties were diminishing in all the groups, at the same time as the level of reasoning and capability was increasing. When they reached the final result by themselves, it not only led to positive emotions but also increased their personal self-esteem and self-efficacy as learners of science.

We consider that the laboratory activity managed to create a learning environment in which personal reflection and learning with others were

valued (Limón, 2001). The students learnt without pressure, with autonomy and self-determination, through expressing, sharing, and justifying their own ideas and actions as well as the emotions that were generated.

The processes of change were favoured through the prospective science teachers' self-reflection. They overcame the negative emotions that their lack of psychopedagogical knowledge had generated, and acquired strategies to self-regulate their emotions and build on their capacity to work with scientific content.

It is necessary to develop laboratory activities in the initial training of prospective science teachers to help them develop metacognitive skills that can contribute to improving their quality as teachers. These skills will enable them to recognize the source of their problems or difficulties when they are teaching, and facilitate their self-regulation of changes in affective factors during the process of teaching scientific content. It must not be forgotten that all these prospective secondary teachers come to the profession with a high level of specific content knowledge, but lacking preparation for the teaching and learning of these disciplines (Mellado et al., 2010).

We agree with Sanmartí (2001) in that initial teacher training must give prospective teachers the opportunity, through a process of metacognitive reflection, to become aware of their beliefs and emotions towards science in general, and towards scientific training and their classroom practices, so that they can self-regulate and modify those beliefs and emotions, and thus forge their personal model of teaching.

Increased self-efficacy in teaching helps prospective teachers to better cope with difficult situations in class, makes them feel comfortable, enjoy what they do, and learn new tools to teach better, and facilitates the appearance of positive emotions. If they have low belief in their self-efficacy at teaching, they will be emotionally vulnerable, living the problems in class as a continual threat associated with anxiety (Perre-noud, 1996). If they do not have confidence in their self-efficacy, they will try to avoid school problems, devoting less time to them instead of designing and developing strategies to overcome them (Friedman and Farber, 1992).

An important limitation of the study is the unequal number of participants for each scientific specialty. Most of the students were graduates in Biology, so it was difficult to obtain a representation of other degrees such as physics, chemistry, geology and mathematics.

Declarations

Author contribution statement

F. Cañada: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

V. Mellado: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

M. Brígido, A. B. Borrachero, M. A. Dávila: Performed the experiments; Contributed reagents, materials, analysis tools or data.

E. Costillo: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Appendix. Annex

CALCULATING THE PERIOD OF A SIMPLE PENDULUM				
Sequences	Difficulty Score from 1 (low difficulty) to 10 (high difficulty)	Reasoning Score from 1 (little reasoning) to 10 (much reasoning)	Capability Score from 1 (poorly capable) to 10 (very capable)	Emotions experienced score
1. Initiation	Statement of the problem Identification as an open problem			
2. Hypothesis formulation	Variables the pendulum's period depends on How the exercise relates to your previous ideas			
3. Experiment	Design The problem of separation of variables Reducing measurement errors The problem of the centre-of-mass			
4. Representation of results	Tables of results Plots of results Use of mathematical functions			
5. Analysis	Conclude that it only depends on the length			
6. Search for regularities	Discard linear relationship $T \neq k \cdot L$ (where $k = \text{constant}$) Search for other relationships $T^2/L = k?$ or $L^2/T = k?$ (where $k = \text{constant}$) Scientific inference (through the results, reach the discovery of the law $T^2 = k \cdot L$) The value of the constants in the formulas			
7. Application	Comparison with the literature $T^2 = 4\pi^2 \cdot L/g$ Application to calculating gravity in Badajoz			

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