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The "Box Universe" of 1 m^3: An Activity for Introduction to the Study of Astronomy

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Abstract

This is a report of an activity of introduction to the study of astronomy developed with a group of future physics teachers at a Brazilian public university. Such activity had the goal of giving privileged emphasis to notions of spatiality, alternative conceptions of the participants, and the process of interaction among peers, with the objective of encouraging discussions in regard to their models of the universe. Such models were made explicit from the distribution of the stars throughout the universe, which were constructed from clippings of paper and inserted into the box which represented the universe. The results, which were categorized as miscellaneous, geocentric, heliocentric, and acentric models of the universe, were qualitatively analyzed. Analyses of the activity in the perspective of the participants are indicated and additional considerations are made regarding its use as a resource for teaching astronomy and for teacher training.

1. INTRODUCTION

The knowledge that humanity currently has available regarding the universe is the fruit of a long process of transformation and refinement of ideas through history (Atwood and Atwood 1995). Generations of people have bent to the task and still bend to the task of dealing with the theme that has brought us to the understanding of the cosmos that we have today. But how has school education favored the insertion of this theme in its classes? Or even before that, it is important to ask: How have teachers been prepared to teach content in relation to astronomy?

In the area of teaching of the sciences, as the space for discussion of these questions, researchers have sought forms that give students the opportunity of learning the scientific knowledge accumulated through the centuries, thus involving them in investigation in different fields, such as the initial and continuing formation of teachers, the educational materials, and the methodological strategies, among others (Rodríguez and Sahelices 2005).

For some decades, one of the fronts that has stood out is the investigation of alternative conceptions that learners have regarding the most varied scientific themes, and among them are many related to astronomy (Frede 2006). One of its merits, according to Cachapuz *et al.* (2005), was to question the efficacy of teaching through transmission of previously elaborated knowledge; in other words, the systematic exposition of content by teachers does not guarantee the learning of the students.

Just as indicated in the above research, the study reported here starts from the premise that the alternative conceptions have an important role in the process of teaching and learning, for they should be considered as elements from which the teacher should plan his activities (Lachel, Langli, and Scalvi 2008). The proposed activity has a constructivist orientation as a base, as indicated by Cachapuz *et al.* (2005), for it approaches treatment of an open problematic situation in which learners work with hypotheses and interact in accordance with them.

2. OBJECTIVE

Official Brazilian curricular proposals (Secretaria de Educação Media e Tecnologia 1997), just as has occurred in various other countries (Kalkan and Kiroglu 2007), have increasingly encouraged the presence of basic contents of astronomy from the first years of schooling, which shows the necessity of teachers being prepared for this teaching (Lima 2006).

Based on this presupposition, the subject of Introduction to Astronomy was proposed, with 60 class hours distributed in 4 h weekly, in which 27 students from the Licentiate in Physics course at a Brazilian public university participated. In this work, the introductory activity of the subject will be related (Navarrete, Azcárate, and Oliva 2004).

The subject was planned such that the content would be approached from the macro context to the micro; in other words, beginning with the study of the universe, then the Milky Way, Solar System and, finally, the Earth and the Moon (Parker and Heywood 1998). Beginning then with the study of the universe, some hypotheses and questions arose, which together gave rise to the objective of this work. Thus, upon planning the introductory activity to the subject, questions were made regarding the understanding that the participants, licentiates in physics, had regarding the structure and organization of the universe (Pedrochi and Neves 2004). Starting from the presupposition that they have alternative conceptions that differ in some degree from scientific knowledge, as already indicated by the works of research cited above, how can their knowledge regarding the theme be mobilized so that they recognize their possible limitations and seek to expand them in the direction of the current scientific models? And furthermore, what activities can be employed in teacher training so as to attend to the important aspects indicated by Libâneo (2002), that is, those aspects that promote structuring of the ideas of the licentiates, analysis of their right and wrong answers, expression of their thoughts, and resolution of problems?

Based on such questioning, this work has the objective of relating how planning and intervention were performed and what the results of an activity directed toward the teaching of astronomy were, developed as an introductory element to the subject of a licentiate course and which gave privileged emphasis to notions of spatiality, the alternative conceptions of the participants, and the process of interaction among peers. Analysis of the results was undertaken from a qualitative approach, taking the images of the accomplished activity as data, as well as the declarations of the participants in respect to the process they underwent (Puzzo 2006).

3. DEVELOPMENT OF THE PROPOSAL

This work was inspired by the research of Afonso López *et al.* (1995), with students of different ages, and of Rodríguez and Sahelices (2005), with adults, who dedicated themselves to examining the mental representations of the universe that such groups have, identifying ideas regarding the Earth and its association to the rest of the universe. As the beginning activity of this subject, the licentiates participating in this work had the problem of representing the universe that they knew, and they needed to indicate the location of the planet Earth within their representations, just as in the works previously cited (Trumper 2003).

Nevertheless, such previous research used, as a strategy, the investigation of the participants' models of the universe based on two-dimensional representations, making use of drawings, schemas, and written texts (Trundle, Atwood, and Christopher 2002). The activity reported here makes use of the construction of a three-dimensional model of the universe that involved the spatial distribution of the heavenly bodies, in a process of contraposition of ideas among the participants (Trundle, Atwood, and Christopher 2006).

The choice of the three-dimensional model is due to the fact that the materials to which the students have access on a daily basis are generally restricted to two-dimensional figures, which do not always respect the true dimensions of the heavenly bodies and the distances between them (Leite 2006; Friedman 2008; Furutani 2008). Some research has indicated favorable results with the use of experiments with three-dimensional models, as for example, Yair *et al.* (2003), Leite (2006), Friedman (2008), and Rosvick (2008).

The activity presented here was conducted in the following way: The licentiates were organized into five teams such that each team received eight wooden sticks, a screwdriver, a roll of nylon string, a pair of scissors, and some sheets of white sulfite paper. Each stick was 1 m in length and had small holes throughout its entire length, and at each end there was a screw that permitted the sticks to be joined, forming the structure of a 1 m^3 box, which the students were asked to assemble. The schema below represents the structure after assembly, which was designated as the "box universe."

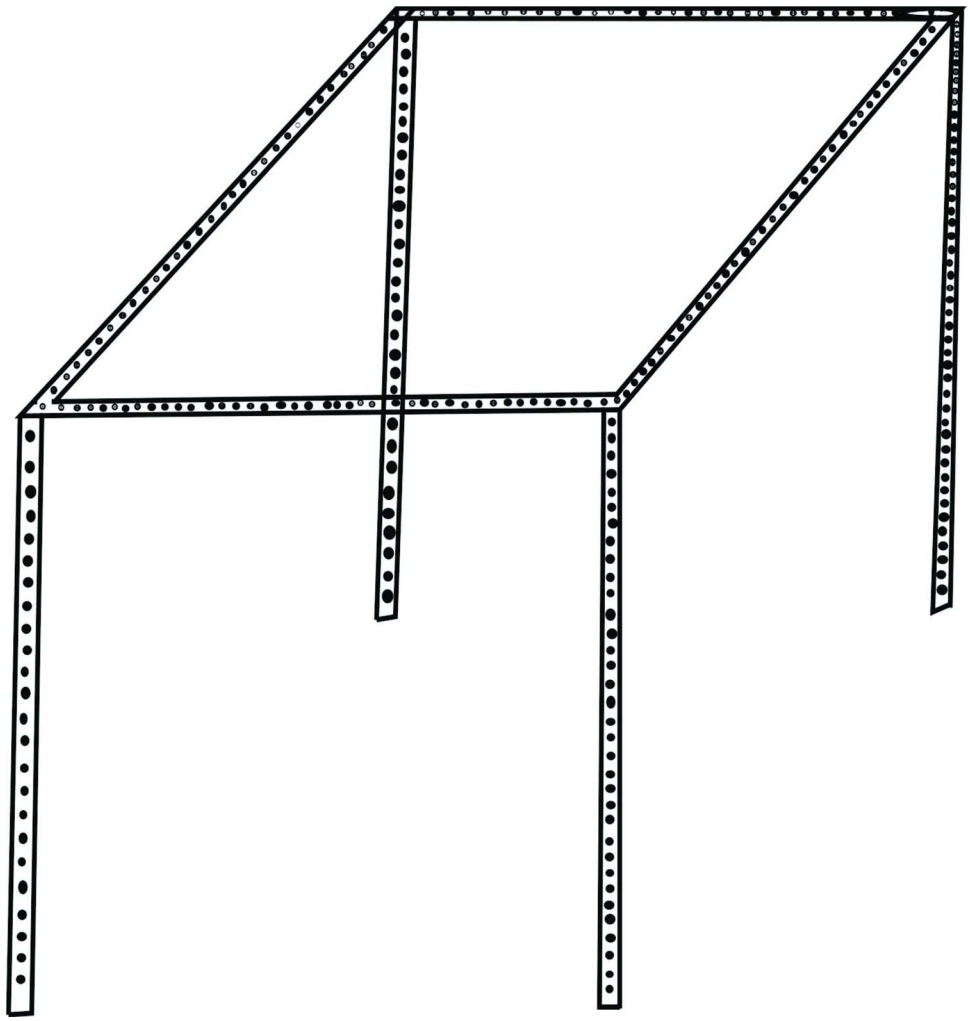


Figure 1. Schema representing the assembly of the 1 m^3 box

Using the sheets of paper, the licentiates were asked to fashion the heavenly bodies they knew or wished to know, which needed to be inserted in their box universes. For this purpose, they were able to freely choose how to use the paper, as, for example, cutting out figures, folding, wadding up, etc. Then the heavenly bodies needed to be distributed throughout the "universe" of 1 m^3 in volume, using the string to fasten them in the positions they desired. The strings were fastened to the sticks using the holes present in them. It is important to emphasize that the teams were also required to explain where Earth would be located in the models they created.

This activity generated intense negotiation among the members of each group since it involved the conceptions that each one had regarding the dimension, format and location of each heavenly body in the volume available. The role of the teacher was to encourage discussions among the participants such that different

conceptions could be appreciated and analyzed within the peer groups. The teams spent approximately four hours in assembly of the boxes, discussion regarding the heavenly bodies that would be inserted, how they would be made and their distribution in the box universes.

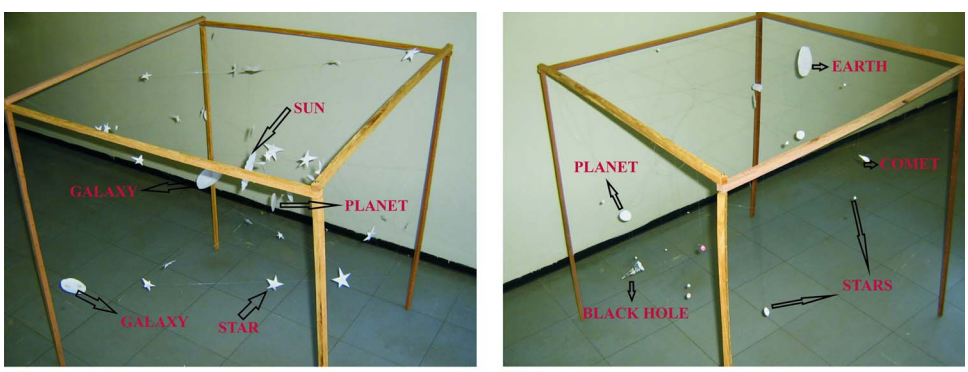
The models obtained were analyzed and organized according to the different conceptions of the universe that the teams presented. The categories of analysis indicated by Afonso López *et al.* (1995) and Rodríguez and Sahelices (2005) were used. The authors classified the responses of the students taking into consideration elements, such as the representation of the planet Earth and of the Sun in relation to the rest of the universe, as well as the distribution and size of the stars in relation to the other heavenly bodies. As such, the four categories that the researchers identified were "bag" or miscellaneous universe, geocentric universe, heliocentric universe, and acentric universe (Vega Navarro 2001).

In the bag or miscellaneous universe were gathered the models in which the heavenly bodies inserted appeared to be loose, without relation to scale or distance, as if they were in a bag. In the models gathered in the geocentric universe, Earth received a highlighted position in relation to the other heavenly bodies, generally in a central location, surrounded by the others. In the heliocentric universe, it is the Sun which stands out, such that the other heavenly bodies turn around it. Finally, in the models classified as an acentric universe, the Sun does not assume a distinguished position, but rather the fundamental units represented are galaxies, such that there is no position that stands out for any one of them, nor even a center taken as reference.

4. RESULTS OBTAINED AND DISCUSSION

The data presented are images made after the five teams had finished the elaboration of their box universes. The results show that among the four categories previously indicated, three of them were present: Two groups assembled their models in accordance with the bag or miscellaneous universe and one group represented it in accordance with the heliocentric universe and two according to the acentric universe. No team constructed a model taking the Earth as the central position, which indicates that, at least in regard to the student participants, they appear to have gone beyond the geocentric conception of the universe.

The images that represent the categories present are presented below. So as to facilitate the reader's understanding. Labels were later inserted into the images through a computer program.



(a) (b)

Figure 2. Box universes within the category bag or miscellaneous universe

It can be seen in both models that the heavenly bodies are dispersed in a random way, such that the stars are generally represented using points, while the planets are circular. There is no understanding regarding the way that the stars are distributed, nor their distance from us, the view prevailing that they fill the empty spaces of the universe, or are in company with other heavenly bodies (Liu 2005) or that they are within the Solar System (Agan 2004). In these models, some other heavenly bodies are present, such as comets or black holes, but they do not maintain any relationship to the others, nor abide by distance or dimension.

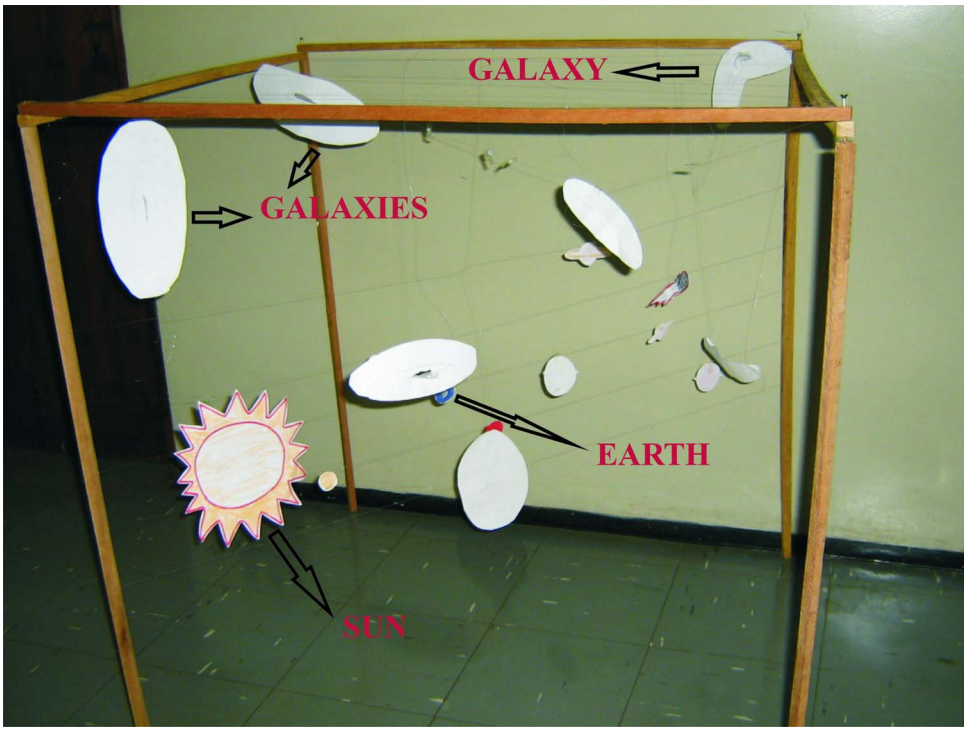


Figure 3. Box universe within the category heliocentric universe

In the image, the marked presence of the Sun can be seen, as well as some planets, represented by the smaller circles, and galaxies represented by the larger circles. There is also no consideration in regard to the distance between them or their distribution within the universe.

In regard to the importance that the students attribute to the Sun when compared to the rest of the universe, two hypotheses are suggested: Either they believe that, in fact, it is the center of the universe, or that the cosmos is restricted to the Sun and to the planets that orbit it. Such results are similar to those obtained in the research of Friedman (2008) in which many students considered the Sun and the Earth as the sole members of our galaxy, or otherwise did not distinguish the Milky Way from the Universe, considering them as synonymous. It is important to highlight the results of studies such as that of Agan (2004), which shows that students differentiate the Sun from other stars principally due to its size.

(a) (b)

Figure 4. Box universes within the category acentric universe

The two models presented represent the distribution of the galaxies in the universe according to an acentric conception. In case (a), they are symbolized by wadded papers and placed in a random way; in (b), they are in

different formats, also placed in a dispersed manner. The Sun and the planets, as well as the Earth, were represented by a small point in one of the galaxies, without necessarily being located in a central position.

Therefore, the models that draw near to current understanding in regard to the organization of the universe are in this category. In them, the students did not designate a preferential center, making the position of the Solar System and, consequently, the location of the planet Earth, a relative thing. They also reveal the small dimension of our planet when compared to the entire universe.

Continuing the beginning activity of the subject, after the elaboration of the models, each team presented its box universe to the others. It was a new opportunity for exchanging ideas since the models represented fundamental differences in respect to the understanding of the structure of the universe presented by each team. At this time, the teacher indicated the differences between the groups and commented on aspects such as the presence of stars among the planets, the distance of the galaxies from us and the dimension of the Earth in relation to the rest of the universe.

The introductory activity of the subject was concluded with the presentation of the documentary "Cosmic Voyage" (Viagem cósmica 2002), which allowed the viewer to visualize a trip from a point on the Earth up to the limits of the universe, dealing with the scale of distance in which the heavenly bodies are found and with our size in relation to all things. Within the ensuing discussion regarding the documentary, the teacher was able to indicate the nonexistence of a center of reference for the universe, whether it be centered on the Earth, on the Sun, or on our own galaxy. This therefore led to considerations regarding the "acentric universe" as being the model nearest to that currently accepted by the scientific community, closing the development of the initial activity of the study of astronomy.

The following classes of the course were dedicated to the examination of other themes related to the area, such as galaxies and the Solar System, an examination which we believe was aided by the fact of the students having a broader conception regarding how the stars are distributed through the cosmos, after the initial activity presented here.

5. CONSIDERATIONS REGARDING THE ACCOMPLISHED ACTIVITY

Some comments are presented below regarding the accomplished activity in the perspective of the participants so that one may understand how it contributed to gaining awareness of one's own conceptions and the importance of the process of interaction within the peer groups, providing for appreciation and respect for the ideas of the participants.

Initially, reflecting on the accomplished activity, it may be affirmed that the representation of the universe in a small space seems to have generated a feeling of incomprehensibility in some students, as seen in the comment below:

> Upon beginning the activity of representation of the universe on a sheet of paper, a question arose: How to represent something that I cannot measure? Measure no, I'll be less rigorous, something that I can't see up to where it goes? (Student T.S.)

According to Rodríguez and Sahelices (2005), people do not always have awareness of their own ideas of the universe, which makes many individuals feel perplexed and in difficulties before the task of having to represent it, perhaps because of the fact of it being the first time they are impelled to think about it.

Although no team represented a geocentric universe, comments on the activity revealed how difficult it is to make the position of the Earth relative, even among students in a university course. The report below indicated the difficulty that was felt in assuming a position in which the Earth would no longer have a highlighted role:

> It may be perceived that, in general, when we are going to make a representation of the universe, it is quite complicated not to attribute a place that stands out for the planet Earth, and the task becomes even more difficult when, as in our case, it is necessary to indicate the location of the Earth. It is even possible to conclude that when one wants to focus on this type of representation, leaving behind the idea of the Earth as a central point, in most cases it is the Sun which is taken as a central reference. (Student J.M.)
>
> Overcoming the concept that we are the center of the universe and perceiving that we are not more than a pitiful point in the infinite makes us see all there is from another angle and not simply from the conception of the starry sky upon looking upward on an average night. (Student A.P.)

The activity appeared as an important element in recognition of the limitations of the ideas that the participants had, which may represent a step in the direction of broadening the ideas or modifying them as indicated in the following reports:

> In the representation of the universe in a cube, we can observe that even we, university students, have in most cases a wrong idea about how the universe is. (Student S.)
>
> A difference that stood out to me was the characteristic of me having represented a greater agglomeration of galaxies in the center of the universe, even knowing that I do not have sufficient advance knowledge to infer that the universe has a center, nor that this agglomeration of galaxies actually exists. It is my conception and what I believe. A conceptual deficiency becomes evident, which is that of drawing some stars as points, even knowing that points are mere optical effects, and that in my drawing the understanding was given that there are stars among the planetary orbits, even though I know that this does not in fact occur. (Student A.N.)
>
> I filled the cube with stars. I know that I committed mistakes for now, after thinking more, I don't think there are stars between the galaxies. What is there between the galaxies? I don't know! That's it, galaxies were missing in the schema, for I "stuffed it" with stars of various sizes, including those larger than the Sun. (Student T.S.)

In regard to group work, evaluation made by the participants showed it to be a positive aspect in the contraposition of ideas and the recognition of the limitations of their schemas, as shown by some statements:

> When they were to represent the universe in a 1 m^3 cube, the members of my group had various ideas; the stars were represented with a spherical format with pieces of chalk, black holes. Also the solar system in this universe was represented with the Sun much larger than other stars. The other stars were uniformly distributed; in other words, the galaxies were not represented. I consider that the F. group was that which best represented the universe, and my group did not represent the galaxies, put the sun and the planets much larger than the other stars; in other words, the universe was not according to scale. And the distance between the stars was much nearer than in reality. (Student Y.)
>
> In the representation in three dimensions that we made in group, we gave more emphasis to the representation of the Milky Way, in which the Sun also was part as the center of the universe, even though our scales were not well represented. In not having a more detailed vision of the universe, I represented it without any physical logic, without obeying structures, scales, and location. (Student L.)
>
> Upon representing the universe in a box, in an activity performed in a group, during the discussions and opinions that arose for the construction of the work and the interventions of the teacher, I verified the distinct denominations and the different parts of the universe. As such, I perceived that that vague idea from primary school was wrong. The solar system is simply a minuscule point in the universe, and the universe is composed of other elements: Various galaxies and their forms, diverse planets, black hole, comets, among other things. For this reason, questioning regarding what was to be done and our work with the box, increased my vision in this respect. (Student M.C.)
>
> The group, in a general way, came into agreement. The attempt was made to put the heavenly bodies in the smallest size possible, for we imagined that the proportion would be more coherent. In spite of that, we placed the solar system in the center of the cube and in a larger size because it involved our reference point. Discussing our model in the classroom, it became clear that we only managed to represent the inside of one galaxy, namely, ours. (Student M.)
>
> The elaboration of what would be the universe in a cubic meter was something that caused conflict for me; first, because I had to make people from my group accept the way I wanted to develop the work, showing that their ideas were not coherent; and, then, due to the advance judgment of other people because the work of my group did not have little stars with points or something similar; but compensatory when the others understood what those wadded up papers were. (Student F.)

6. CONCLUSIONS

The results obtained corroborate with those from other research undertaken with the same themes, which are, the mistaken distribution of the stars in the universe (Furutani 2008), a universe constituted of the Sun, Earth, Moon, and some stars (Liu 2005), universes centered in the Sun (Morais *et al.* 2005) and difficulties of representing the heavenly bodies in a three-dimensional way (Leite 2006). According to Rodríguez and Sahelices (2005), simplistic models of the universe present among students and even among teachers reveals the lack of importance that has been given to education in astronomy to these teachers, who will have the task of teaching such content.

Further, regarding the models, it was seen that even when they represent the observable heavenly bodies, the students appear to be very fixed on that which they observe in their day-to-day experience; in other words, a sky such as a "circus tent," where the heavenly bodies are distributed, without considering that many are light years away. It seems there was not precise understanding regarding the difference between the apparent distance and the real distance of the heavenly bodies.

Regarding the activity performed, it may be said that it showed high potential for introduction to the teaching of astronomy, for it gave the opportunity for the students to connect, in a single activity, in a three-dimensional space, the most diverse ideas on themes from the area. The limit imposed by the 1 m^3 space and the demand of representing the location of the Earth were aspects that enriched the activity, for the licentiates had to work with scales of size and distances between the heavenly bodies.

The use of this activity in the teaching of astronomy is strongly promoted since in this science many aspects are hard to visualize, and activities must be invested in which employ spatial relationships. As they are not observable aspects, this implies that the students must learn to construct the spatial relationships among them, as affirmed by Leite (2006). Nevertheless, the results proved to be fruitful when this construction arises from the ideas of the participants, in a process of interaction among peers. This is one of the tasks of the courses in teacher education.

In spite of the favorable results, we do not wish to affirm from this that the simple involvement of the students with a problem, with the offer of materials, raising hypotheses and interaction among peers, mediated by the teacher, guarantee the learning of the participants, as if they could learn the scientific content all by themselves. The systematizing of such content based on readings and other materials is fundamental. What must be emphasized here is that activities of this type, in addition to giving the teacher a panorama regarding the knowledge that their students have, something to be considered (Scarinci and Pacca 2005), also prove to be a fertile moment of exposure to and debate of ideas, of effective participation of future teachers, something that is desired in their future professional practice and that teacher education courses have not always developed in an effective way.

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