Elementary preservice teachers' knowledge of astronomic phenomena: what can be done

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Abstract

Using natural phenomena to scaffold children's inner interest in doing questions and seeking for answers are current orientations to early childhood education. Recent research has shown that children at preschool bring unsuspected abilities in learning. Since some elementary astronomic phenomena are an everyday experience they should integrate the pool of resources from which the educators withdraw their material to promote an intentional teaching.

This brings to the fore the assessment of preservice teacher education in basic astronomic phenomena, their previous education in this subject and the robust misconceptions they hold.

This study report on misconceptions held by preservice elementary teachers and educators in a higher education institution in Lisbon. We had developed and validate a closed questionnaire constructed to probe the understanding of basic astronomic phenomena (day and night, moon phases and movements, earth movements, stars and constellations). Among the answers provided in the questionnaire were present as distractors misconceptions reported in the literature, so they could be assessed.

The questionnaire was applied in 2017 and 2018 before and after the teaching and learning module of astronomy. Here we will work on the answers obtained in those years before the teaching and learning module.

After a descriptive statistical analysis of the responses, we proceed to group the answers in main alternative conceptions and assess how prevalent they were among preservice teachers before they attend the module in elementary astronomy.

The results show, as expected, a similar distribution of alternative conceptions before the teaching and learning module in 2017 and in 2018. The Moon movements and its phases are poorly understood; the explanation for the seasons rest largely in the distance to the Sun framework; the apparent movement of the stars (and constellations) in the sky are detached from the apparent diurnal movement of the Sun. Scales are poorly understood and the Universe is seen as being much smaller than it is.

We conclude showing how the two main conceptual change frameworks, the Vosniadou's 'Framework theory" and diSessa's "knowledge in pieces" explain our results and hint on what future work can improve our teaching and learning on elementary astronomy.

Keywords: elementary astronomy, preservice teachers, conceptual change, p-prim, framework theory

1 INTRODUCTION

Astronomy and Space are fields of knowledge firmly established in the curriculum of preservice teachers' initial training at the School of Education of Lisbon. This is justified by its importance on its own but also by what is in the curriculum at elementary grades as well curricular guidelines to kindergartens in Portugal [1]–[5]. Basic astronomic phenomena are a teaching and learning subject from the first to fourth grade in accordance to Bruner spiral curriculum. Then is covered, now in a unique stroke in the seventh grade. At this level is the subject of the teaching and learning match with the content knowledge that is subject to our own teaching and learning in the preservice teacher course. In spite of this (or because of it?), students come to college with an overwhelming presence of alternative conceptions that hamper their understanding of further astronomical phenomena and, most probably, will influence their pedagogical activities. These are the issues that led us to seek some explanations for the existence of the reported alternative conceptions, their persistence and how they could be surpassed.

Broadly speaking, alternative conceptions are knowledge that students bring to the classroom that is not in accordance with actual scientific understanding ([6], [7]). Or, using Ausubel dictum, it constitutes part of the most important single factor influencing learning. Most of those knowledge do not offer problems to the teaching and learning process and adapt to the correct scientific claim without much problem. Other knowledge is much more resistant to change and persist in time. This research seeks to inquiry in the later.

Andrea diSessa hypothesized the existence of what he named phenomenological primitives, or p-prims for short. They are phenomenological because they originate in the most common daily life experiences and, also, because once formed constitutes a rich vocabulary to interpret the phenomena; they are primitives since they cannot be explained by any knowledge structure but are explanatory pieces ([8], [9]). In this framework, learning science imply the activation of some p-prims, instead of others, and their aggregation in larger entities able to explain the phenomena. The p-prims that are activated are much context dependent. For example, the formulation of a question may cue the activation of one p-prim while a little reformulation of the question would activate other. A most cited example of a p-prim is the "Ohm's p-prim" that can be stated as "more effort implies more result"; "more resistance implies less result". "Dying away" is an example of another p-prim which originate from the experience that all motion eventually weakens until it vanish completely. We should keep in mind that p-prims come from the vast sensorial and social experience. It's origin in the field of physics is just a matter of fact related to the development of the experimental studies that was carried out in the field.

According to diSessa, learning occur through the activation, reorganization, addition and accretion of what was a loose net p-prims in an intuitive theory and eventually in a knowledge that mirror the current scientific knowledge [10].

Other framework to explain the process of learning by conceptual change was developed by Vosniadou and her group ([11], [12]). Contrary to diSessa's, the learner come to the classroom with a theory-like mental model which Vosniadou named "Framework theory." It is a highly organized conceptual structure with a set of ontological and epistemological presuppositions and a system of beliefs originated in the cultural and observational context of the learner that led to the formation of the mental models of the phenomena, a specific theory. In this context, learning occurs through the enrichment and diversity of cultural and observational experiences specifically designed to highlight a targeted phenomenon with an explicit discussion of ontological and epistemological assumptions.

Vosniadou did accept diSessa's p-prims but integrate them in their theory-like framework as the result of cultural and observational experiences. For the framework theory, alternative conceptions are formed earlier in child development and, if well understood, can constitute the basis for ulterior learning. The fact that they exist cannot be removed and is not in itself a bad or a good thing. Is just what it is. For diSessa's p-prims framework, alternative conceptions are formed in the process of learning with the activation, organization, addition or remove of p-prims. Knowing this, students could construct new knowledge closer to the scientifically accepted, if teachers' cue the activation of the right or more productive p-prims – in relation to the phenomena in study - and work over them.

In the following section we describe the methodology used in this study, after which we present the results. This presentation will be interwined with a brief discussion of the results and the tentative of explaining them in the conceptual constructs of Vosnaidou and diSessa. Then we conclude with a discussion of our results directed to the improvement of the learning and teaching of the basic astronomic phenomena.

2 METODOLOGY

In 2017 we developed a questionnaire to assess elementary preservice teachers' knowledge on basic astronomic phenomena at a college in Lisbon [13]. The questionnaire with 21 items was piloted and then validated by two experts presenting a Cronbach alpha of 0.603. In 2017 and in 2018 the number of accepted responses in the first application of the questionnaire was of 61 - two or three respondents don't answer a great number of questions and thus prompt us to eliminate them from the study. Almost all respondents were females. After its first application before and after the didactic intervention on

astronomy in 2017 we decided to change some items of the questionnaire in order to surpass some shortcomings that arise in the meantime. However, except for 3 questions, the results of all others 19 remain comparable. Here we investigate the answers of the students before the didactic module of astronomy in 2017 and in 2018. This allows us to probe deeper into the students' alternative conceptions and hypothesize some explanations for their prevalence. To this, we use various items of the questionnaire that aim to understand the same phenomenon or could shed light to the same phenomenon. Also, we use follow-up interviews done after the first application of the questionnaire in 2017 as well as the observation of our own teaching and learning process to assist the discussion of our results. Finally, they will be discussed under the framework of Vosniadou's framework theory and diSessa "knowledge in pieces"([8], [11], [14])

3 RESULTS

Our results will be presented and discussed according to the alternative conceptions (AC) we elicit from the answers. They are gather together in Tab. 1. In what follows we discuss each of them.

Table 1. Alternative Conceptions and their abundance before instruction.

#	Alternative conception	2017		2018	
		n	%	n	%
1	At noon the sunlight doesn't cast a shadow of a vertical stick in Lisbon.	58	95	55	90.1
2	Observed from Lisbon, the stars of the Big Dipper didn't change its shape with time. Even if we were able to change the perspective it remains as we see from the Earth.	52	85.2	54	88.5
3	If the moon keeps the same face towards Earth it can't have rotation.	45	73.8	43	70.5
	a. The moon does not have a rotational movement; hence we saw the same face.	20	32.8	20	32.8
	b. It's not true the Moon has always the same face turn to the Earth	25	41	23	37.7
4	Seasons are due to the distance to the Sun	38	62.3	52	85.2

3.1 First Alternative Conception

The number of answers in line with this AC in 2017 and 2018 are of 95% and 90,1% respectively. The great majority of the answers (83,6% in 2017 and 70,5% in 2018) choose the option that at noon the sunlight never cast a shadow of a vertical stick in Lisbon while a lower number of respondents (11,5% in 2017 and 19,7% in 2018) choose the option stating that a vertical stick didn't cast a shadow only at the first day of summer. This result goes in line with the responses to two other questions aiming to probe how the length of a shadow in Lisbon varies with the day and with the year.
To the question "In which of the following days the shadow of a vertical stick have the shortest length?" 50,8% in 2017 and 63,9% in 2018 choose the correct answer, July 21th. Related to the variation of the length of the shadow during a day, 78,7% choose the correct answer in 2018, "around lunchtime."
From this we can conclude that respondents have a fairly good experience that shadows at noon are shortest than at any other time of the day and in the summer the shadows are shorter than in the winter.

3.1.1. Discussion

According to diSessa's framework, this alternative conception result from the activation of a p-prim when the question is asked and/or the teaching and learning of sun movement is carried out. The p-prim in question would be most likely the one named "dying away". This p-prim, initially found in the study of mechanics, as all others was, refer to something that disappear or get weaker and weaker until fading away. The daily experience of seen the shadow getting shorter when midday approach, or when summer approach could trigger this p-prim and get the respondents to choose the answer that shadow eventually disappear.
Vosniadou's framework theory stress the importance of the ontological and epistemological presupposition of the learner. In this respect, "The sun is overhead at noon" appears to be an ontological belief largely hold by the students.

3.2 Second Alternative Conception

The number of answers in line with this AC in 2017 and 2018 are of 85.2% and 88.5% respectively. Only a residual number of students choose another option. In response to another question present in the 2018 version of the questionnaire, 49.1% of the respondents answered “the stars don’t move one in relation to another” or, else, “only some stars move in relations to another” displaying a static conception of the universe. Adding to this, students hold a poor understanding of the scale of the universe or, alternatively have a Copernican-like view of the Universe that is, the Universe wouldn’t be much bigger than the solar system; or the solar system is all that is.
This is sustained by the number of answers students present when asked what the distance between Earth and the stars we see at night would be, if the distance between Earth and Pluto were reduced to 1 cm and all other distances reduce with the same scale. In 2017 and 2018, 85.2% (54), and 73,8% (45), respectively, choose the options between 1 to 10 cm. From these 47.5% (29) in 2017 and 41% (25) in 2018 opt for the options according to which the stars would be about the same distance as Pluto or even near. Follow-up interviews conducted in 2017 evidence that this was not some mistake, but a conception really held by the interviewees.

3.2.1 *Discussion*

In the “knowledge in pieces” framework, this alternative conception result from the activation of a p-prim, the “continuous push” or the “actuating agency” in the more general Hammer and Helby [15] terminology. Students hold a fragmentary understanding of the actuating forces in the Universe. In a test applied immediately after the astronomy module, some students couldn’t identify gravity as the force responsible for the existence of galaxies. We hypothesize students do not consider an actuating agency in deep space, so motion is ill understood, if it is at all. When motion is considered, that is due to Earth rotation, an actuating agency that allows students to make sense of the conjoint movement of the celestial bodies as the Ancients did.
This misconception, in the framework theory, is explained by ontological presuppositions. Namely, the conflation between the Solar System and the Universe: they are understood as having similar magnitudes. From this, some other issues arise, like an ill understanding of how gravity can be so weak and so powerful at the same time.

3.3 Third Alternative Conception

Students holding this AC apparently cannot reconcile the existence of rotational movement of a body with it showing the same face in a given direction. So, we went a little further in the exploration of this AC, evincing how student’s split between the ones believing the Moon doesn’t have rotational movement and the students that deny the statement in que question, “When looking to the Moon from the Earth, is seen always the same face.”
The number of answers in line with this AC in 2017 and 2018 amount to 73.8% (45) and 70.5 (43) respectively. Students split almost equally between the ones affirming the Moon does not show the same face towards Earth (41% in 2017 and 37.7% in 2018) and the ones stating the Moon does not turn around its axis (32.8% in each year). This difficulty in cope with lunar movements is also shown in two other questions. One, probing the time Moon takes to complete a full orbit around Earth shows that 32.8% of students opt for 1 day in both years the questionnaire was applied. Also, 41% in each year, answering the question “If we see the Moon, in full Moon rising East, what would be it aspect 6 hours later?” opt for the first or third quarter. These results show students’ belief in a fast-paced movement of the Moon.

3.3.1 Discussion

In the knowledge in pieces framework, this AC result from the activation of the p-prim “face of the coin” that we posited following diSessa [8] heuristic principles to identify p-prims. This p-prim is almost self-evident, as it should be. It says we cannot see at the same time two faces of a body; moreover, it should rotate if we are to see the other face. In kinesthetic teaching and learning activities related to the movement of the moon - represented by a student - around the Earth – represented by another student – a significative number of groups show great difficulty in reconcile the two statements present in this AC, that is, the Moon shows the same face towards Earth and the Moon rotates on its axis. Even when

they perform the rotation and translation as they should, at the end of a translation many students still think they do not rotate.
Adding to this, it is not obvious to students that the Moon shows the same face towards the Earth. Despite this is a statement in que question, around 40% of the students refute it. The poor relationship between students and general population with the sky due to city lights and deprived clear night experiences don't help in the process of overcoming this AC. Part of the class time is nowadays spend in showing that when we gaze at the moon we can only see one face, if illuminated by the Sunlight.
This misconception, in Vosniadou's framework theory, is explained by the conflation of translation and rotational movement (ontological presupposition) and by poor observational and cultural information in the specific theory.

3.4 Fourth Alternative Conception

This widespread alternative conception [16] is held by 62.3% (38) and 85.2% (52) of the respondents in 2017 and 2018 respectively. This result is supported by the answer to another question which asks, "In which of the [following] situations wouldn't exist Seasons?" This question has a strong distractor though: "The Earth don't have translation movement" which have 60.7% of responses in 2017 and 39.3% in 2018. Anyway, the students that choose, even with this distractor, the option "The Earth keep the same distance to the Sun" come to amount to 19.7% in 2017 and 47% in 2018.

3.4.1 Discussion

In diSessa's framework this AC result directly from the activation of the p-prim "dying away." This p-prim is directly related to the common experiences of light becoming week while the distance increase, or, hot sources become hotter when we come closer. In this respect, the question we use to probe this misconception ("Imagine the Earth orbit around the Sun would be changed to become a perfect circle in such a way that the distance between Earth and Sun never change. In what way that would affect Seasons?") is more akin to cue this p-prim than the question with the strong distractor we refer to above. As we can easily see, this p-prim isn't wrong. It is not sufficient in itself, as none is, to form a scientific understanding of the phenomenon. What is missing is the angular dependence of the surface towards the light source of light or energy intensity.

In Vosniadou's framework theory, this alternative conception would be explained by a strong observational and cultural information. Note that the perception that light or energy fade away with distance is overwhelming present in our daily-life, whereas the angular dependence is not experienced, or, is experienced but we attribute it to other causes. Also, in Vosniadou framework the ontological belief that in the summer we are close to the Sun is another factor to add to the already mentioned. In several cases, when we explicitly say to the students that the Sun is closer to the Earth around January 3th, a winter day, they still interpret the sentence "The northern hemisphere is more directed to the Sun in the Summer" as saying that it is closer.

4 CONCLUSIONS

We have found and discussed four highly prevalent alternative conceptions with our questionnaire: "At noon the sunlight doesn't cast a shadow of a vertical stick in Lisbon"; "Observed from Lisbon, the stars of the Big Dipper didn't change its shape with time. Even if we were able to change the perspective it remains as we see from the Earth"; "If the moon keeps the same face towards Earth it can't have rotation" and "Seasons are due to the distance to the Sun". These results are consistent to what the literature report as prevalent alternative conceptions[17][18].

The alternative conception expressed by the sentence "At noon the sunlight doesn't cast a shadow of a vertical stick in Lisbon" is, as discussed above, much related to the daily life experience. In the p-prims framework, this alternative conception come to the fore when students were taught in astronomy from the first grade to the fourth and then in the seventh grade in conjoint with the daily experience of seeing the shadow "fading away" as the Sun is getting closer and closer to be overhead. To work on this AC, the teacher could work several instances in which things appear to disappear but at a closer look they are still present. This will require from student's attention to the detail.

In the framework theory, the teacher should address the belief that the sun is overhead at noon. This could be carried out while enriching the experiential repertoire of the students. In both frameworks, is understood that this cannot be done in a short period of time.

The alternative conception expressed by the sentence “Observed from Lisbon, the stars of the Big Dipper didn’t change its shape with time. Even if we were able to change the perspective it remains as we see from the Earth” would be related to the activation of the p-prim “actuating agency.” In the seventh-grade students are subject to a teaching and learning of astronomy that is essentially observational. Curious enough, gravitational forces are integrated in the explanations of the system Earth-Moon as if stars and galaxies were “up there” without forces between them. Also, the fact that gravitational force is so weak and at the same time is the one responsible by large scale structures and its dynamics clearly prompt the activation of the actuating agency p-prim. The teacher could then work gravity and its effect at a larger scale in order to work upon the activated p-prim. In the framework theory teachers could work on the presupposition of what is an asterism, a constellation and the historically situated nature of their schematic representation. Again, this is a time-consuming effort.

The alternative conception expressed by the sentence “If the moon keeps the same face towards Earth it can’t have rotation” could be tackled by kinesthetic teaching and learning. This would prompt students to experience the actual movements of the Moon and Earth thus working upon the “face of the coin” p-prim. At the same time, the different scale (1 day, 1 month, 1 year and the possibility of eliminate one while considering the other) on which those movements occur should be included in the kinesthetic experience. The framework theory would ask for complementary intervention, namely showing that the Moon really presents the same face towards Earth, through, for example, of increasing the number of observations of the Moon both in the present as well as historic records. Also, working on several instances to show that every movement is a composition of a translation and a rotation and the need to ignore one while the teaching and learning occur would be necessary to overcome the conflation of both movements.

The alternative conception related to the cause of the seasons, could be worked out by using the already activated “dying away” p-prim and work the angular factor. That is, the distance to the source of heat can be kept constant and at the same time the intensity of light/energy is increased or diminished. Also, in the framework theory, evince that the Earth is closer to the sun in the winter could be valuable but could also be detrimental for reinforce the “dying away” p-prim. An alternative or complementary approach could be to see how much the angle towards the source of light affect the amount of incoming energy. The fact that the Earth is quasi-spherical imply a diversity of angular orientations of its surface towards the Sun.

ACKNOWLEDGEMENTS

The project of which this paper is part was funded by CIED with the reference: ESELX/IPL-CIED/2016/A25

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