COASTRO: @N ASTRONOMY CONDO – DEVELOPMENT OF TEACHERS' KNOWLEDGE OF ASTRONOMY THROUGH A CITIZEN SCIENCE PROJECT

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Abstract

Public awareness of science-astronomy (PASa), in the particular case of Astronomy, can be considered satisfactory when compared to other sciences. The public and, in particular, the elementary school teachers, show to be interested and have a positive attitude towards Astronomy. Yet, they reveal lack of knowledge and lack of consciousness about the processes studied in this scientific field. Thus, we need to develop the public understanding of science-astronomy (PUSa) which can take place in a dialogical and participatory matrix of public engagement with science-astronomy and technology (PESaT).

In this context CoAstro: @n Astronomy Condo emerged – a citizen science project based on the involvement of elementary school teachers, with the Research Group on the “Origin and Evolution of Stars and Planets” at the Instituto de Astrofísica e Ciências do Espaço (IA). This initiative aimed, among other things, to promote the appropriation of substantial knowledge of key astronomy contents and scientific processes.

For this purpose, the “Astronomy Questionnaire” (AQ) was elaborated, based on the “Astronomy Diagnostic Test 2.0” (ADT), already tested with teachers, in previously studies (performed by other authors).

To produce AQ we started by translating ADT into Portuguese. This first translation went through a scientific and linguistic validation process. The validated version of the questionnaire allowed us to proceed to the pilot study aiming the facial and content validation. To monitor the teachers' level of substantial knowledge, at the beginning and end of the CoAstro project, the pretest was applied in late 2018 and the post-test in mid-2019. At both times the AQ was answered by 9 elementary school teachers (8 female and 1 male, with an average age of 44.8 years) who volunteered to participate in CoAstro. The teachers had degrees in subjects outside the scientific field of astronomy and they had never taken any specific training in Astronomy.

The results show an increase in knowledge from the pretest (M=20.6%; SD=9.5%) to the posttest (M=36.0%; SD=16.2%). It also shows: i) an improvement in all conceptual categories of AQ (“notion of scale”, “movements”, “gravity” and “general category”); ii) more significant improvements in thematic categories that were most worked in CoAstro and for longer time; iii) less significant improvements in items that appealed to some mathematical reasoning; iv) that teachers at the post-test, despite not being totally confident in their answers, have, at least, an opinion about the items under analysis; v) that teachers´ wrong conceptions at the post-test are different from the initial ones and reveal a evolutive process towards the scientific concept (they are closer to it).

Analysing the evolution of substantial knowledge of key astronomy content will help to better assess CoAstro, by measuring the relevance, of a PESaT citizen science project (which combines remote interactions with systematic bilateral interactions) for a more holistic awareness and understanding of knowledge in Astronomy.

Keywords: Citizen science, Science communication, Science popularization, Astronomy.

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1 INTRODUCTION

Science communication can be understood as any act that aims to promote one or more of the following paradigms [1-3]: i) public awareness of science (PAS) - predominantly about attitudes toward science; ii) public understanding of science (PUS) - understanding of science content, methods of inquiry and science as a social enterprise; iii) public engagement with science and technology (PEST) - the engagement will correspond to an involvement of non-specialists in scientific-technological subjects, under a philosophy of reciprocal learning. The promotion of scientific literacy (SL), in a favorable enviroment of scientific culture (SC), is the ultimate goal of any science communication initiative.

From a PEST perspective, the aim is to contribute to social and economic development through the democratization of problem-solving processes. Thus, in addition to the interaction that enables citizens and higher education institutions, other benefits emanate from PEST [3]: it is inclusive (as it tends to benefit everyone) and is a way towards validation of scientific research. In this paper, when we discuss the results of an astronomy project, we will use the acronym PESaT - public engagement with science-astronomy and technology. Such desiderate appears to be most easily attainable if citizens can be directly involved in the process of scientific production - citizen science.

Thus, we verify the existence of various levels of engagement. A more passive level, where interaction between citizens and experts happens to discuss scientific issues (or their ethical implications). In its antipodes will be an active level, where public authority is given to citizens, which define agendas and policies, through critical reflection on scientific culture, social concerns and priorities. In the gap between these two poles, we have an intermediate level of compromise, where citizens are empowered from the definition of problems to the determination of the solution. It is in this hiatus that we developed “CoAstro: @n Astronomy Condo” project, presented below.

1.1 CoAstro – a citizen science project

Also in astronomy, the term citizen science is used to refer the public engagement in different stages of scientific processes [4-7]. This collaborative concept, between astronomers and volunteers, is becoming an increasingly popular space in non-formal science education [8]. Indeed, citizen science can easily create a win-win context: it attracts more researchers to science communication and, on the other hand, allows the public to participate directly in scientific processes [9].

Thus, CoAstro defines itself as a citizen science project which, during one school year (2018/2019), had the participation of four astronomers, from the Instituto de Astrofísica e Ciências do Espaço (Portugal), nine elementary school teachers, four disseminators and one mediator (these belonging to the Porto Planetarium – Ciência Viva Center – PP-CCV). Under this project, scientific content and processes were appropriated and integrated by teachers into school initiatives, enhanced by the “school effect” and “teacher effect” [10-12]. This allowed the project to be extended to the school community with the engagement of approximately 1000 persons.

CoAstro was organized in work packages. One took a central role in the process: the involvement of elementary school teachers, with the Research Group on the “Origin and Evolution of Stars and Planets” at the Instituto de Astrofísica e Ciências do Espaço (IA). This followed a collaborative model of citizen science [13]: data collection was accompanied by their analysis. Thus, with the approximation between the largest space science research institute in Portugal and the teachers, we intended to speed up the process of transposing knowledge and scientific processes to non-specialized audiences.

To engage teachers in astronomy research, two subprojects were developed in CoAstro: “Stars” (aiming the analysis of a standard stellar spectrum in order to allow the determination of the composition of 57000 stars and the characterisation of their brightness, using *Data Release 2* from the European Space Agency – ESA – *GAIA Mission*) and “Planets” (aiming the production of a planetary transit video, using *Python* program and the analysis of light curves to signal the presence of potential exoplanets).

CoAstro was developed into eight main work packages: three of project dissemination (to astronomers and teachers – October to December 2018); one for the presentation of CoAstro´s participants and analysis of the underlying contents of the Astronomy Questionnaire (“One day at PP-CCV” – January 2019); one for the development of astronomy research (“Astronomical teachers” – January to May 2019); a 25-hour training course (“Understanding the Earth through Space” – March to May 2019); one for the dissemination activities of astronomy in schools by teachers with the collaboration of astronomers and disseminators (“CoAstro goes to school” – May and June 2019) and one for teachers to present the results of their astronomy research to the their school community (“D-Day at PP-CCV” – July 2019).

In the context of CoAstro, it was the role of the mediator to adjust the language, among all project participants, namely by creating the “research task guides”. He also ensured the maintenance of the collaborative work, articulating the challenges of research, dissemination and teaching.

One of the criticisms pointed out to citizen science projects, is their merely instrumental character and, thus, their little contribution to conceptual and procedural knowledge of astronomy, of the participants in such projects [14].Therefore, CoAstro assumed, from its conception, that one of its objectives would be to promote the appropriation of substantial knowledge of key astronomy contents and scientific processes. Thus, it would be necessary to evaluate the teachers' substantive knowledge at the beginning and end of the project, in order to understand CoAstro's contributions to this process. It is in this context that we will now present the process that led to that assessment.

1.2 Knowledge in astronomy: development of questionnaires and case studies

The level of specific knowledge in astronomy was the criterion that led to the option of selecting, as a non-specialized audience to involve in CoAstro, elementary school teachers. In fact, we were looking for the teachers with the lower potential levels of PUSa. They would necessarily be the ones to prioritize in a project with CoAstro characteristics.

Symptom of the conceptual difficulties with astronomy in the elementary school would be the fact that, in its curriculum standards, the moon is considered as a planet [15]: “distinguishing stars from planets (Sun - star; Moon - planet) ”. Moreira [16] analyzed the pre-service teachers courses of the elementary school teachers. To do so, she addressed the curricula and programs provided by seventeen higher education institutions. She concludes that few institutions offer satisfactory training in physical and chemical sciences and it has been concluded that very few properly prepare teachers to teach the required contents. In astronomy, Sá [17] states that there is a gap in the science curricula of initial teacher education courses in the field of astronomy, compromising the effective teaching of this area of knowledge. She also states that it turns out that they correspond to those described in the literature and reflect the lack of this area of knowledge in the study plan of initial teacher education”. This opinion is reinforced by Santos and Sá [18] who point out the gaps in the initial formation of elementary school teachers, in astronomy, which does not allow them to update knowledge or develop skills. Also symptom of the situation just described is the fact that ESERO-Portugal (European Space Education Resource Office-Portugal) had elected the elementary school teachers as one of the groups to prioritize in their work. Thus, this program assumes, from the outset, the need to provide these teachers a solid foundation of concepts and fundamental knowledge about science, related to curriculum subjects of school programs, associated with space [19].

From what we said above, it is understood that one of CoAstro's objectives was to measure what is the substantive knowledge about key astronomy contents, of the teachers involved in the project. This would require the application of a methodologically robust instrument that had also needed to be already tested with teachers. This instrument, which we will present in detail later in this paper and which we call the “Astronomy Questionnaire” (AQ), was elaborated, based on the “Astronomy Diagnostic Test 2.0” (ADT), already tested with teachers, in previously studies [20, 21].

The original “Astronomy Diagnostic Test” (ADT) is a multiple-choice test that evolved from a tool for measuring alternative conceptions in astronomy [22]. It was produced by the University of New Mexico [23], as part of an effort to reformulate introductory astronomy courses. This first version of ADT was restructured by the *Collaboration for Astronomy Education Research* (CAER): a group of professionals from various institutions created specifically in 1998 to produce a multiple-choice test based on research in education (specifically, in assessement questionnaires).

Thus, the original ADT was rewritten respecting four principles [24]: “(1) address concepts included in most introductory astronomy courses for non-science majors, (2) include only concepts recognizable to most high school graduates, (3) focus on one concept only, and (4) avoid jargon ”. This new instrument, called ADT 2.0, expands the original by including questions from the *Science Teaching through its Astronomical Roots* (STAR) project: a project that brought together astronomers and high school teachers to establish course content and methods as well as to create materials for students of these courses [25]. CAER's work, compiled by Hufnagel [24], also ensured that the content tested was included in the *National Science Education Standards*: the USA “curriculum”.

Experienced astronomy teachers, with high knowledge of the National Science Education Standards, made the ADT 2.0 validation process. In addition, contributions from other non-CAER personalities, with experience in teaching and research in astronomy education, were included.

The reliability of ADT 2.0 has been achieved by combining three factors [26]: (i) performing a statistical analysis of 2000 tests from 34 classes (from 21 institutions) from all over the USA territory; ii) the analysis of 30 written responses, produced by students who received the ADT in a version, purposely without multiple choices; (iii) 60 interviews with students enrolled in the aforementioned astronomy introductory courses at the University of Maryland and Montana State University.

The end result of this CAER work was ADT 2.0, released in June 1999. It consists of 33 multiple-choice questions: 21 on astronomy content and 12 sociodemographic issues [21]. In 2000, the National Science Foundation awarded a research grant that extended the application of ADT 2.0 to classes and educational institutions across the United States, thereby increasing the number of respondents. This initiative was even known as the “National ADT Project”. The national ADT 2.0 sample included more than 5000 pretests and over 3000 posttests of 97 courses from 1999 to 2001 [27]. The pretest average was 32.4% (standard error – SE – 0.21%) and the post-test average 47.3% (SE=0.32%).

Brunsell and Marcks [20] later applied ADT 2.0 to teachers. In their study, they used the 21 content questions, with 142 teachers: 43 from elementary schools, 73 from middle schools and 26 from high schools. The results revealed the following test means: elementary school teachers – 35% (SD=13); middle school teachers – 50% (SD=16); high school teachers – 64% (SD=12).

Turkoglu, Ornek [21] also applied ADT 2.0, in Turkey, to 113 pre-service science and technology teachers. The average of these teachers' tests was 34.2%: slightly above the average (32.4%) of Deming [27] pretest and in line (35%) with the elementary school teachers results of Brunsell and Marcks [20].

2 METHODOLOGY

The above description justifies the choice of the ADT 2.0, as the basis for the Astronomy Questionnaire (AQ), applied to teachers involved in CoAstro. In fact, other instruments have been analyzed, some of them more recent. However, they were either very specific, dealing with a limited number of astronomy concepts [28, 29]; or, like the *Test of Astronomy Standards* (TOAST), “addresses… the full range of topics commonly taught in a one- or two-semester undergraduate introductory astronomy survey course” [30]. In fact, ADT 2.0 seemed to be: i) more oriented towards respondents trained in non-scientific fields (such as CoAstro teachers); ii) have content closer to the compulsory education in Portugal; iii) with more applicastions to respondents including elementary school teachers; iv) with application experience outside the USA educational context.

Therefore, in this chapter we will characterize the AQ respondents and the whole process that, starting from ADT 2.0, led to the adaptation, validation and application of the AQ used in the CoAstro project.

2.1 Astronomy Questionnaire (AQ) used in CoAstro

2.1.1 Adaptation and validation of the questionnaire

In order to produce the AQ we started by translating ADT 2.0 into Portuguese. At this stage, the most common metric units in the USA (feet, inches) were converted to those most commonly used in Europe (m, cm, mm). This first translation was the subject of a scientific analysis by an astronomy expert. In this analysis, the expert verified the need to make minor adjustments in the translation, in order to avoid changing the meaning of the scientific content of ADT 2.0. We also reflected about changes that we need to made due to our location (Portugal) being different from the one where ADT 2.0 was produced (USA).

Subsequently, a graduate person, working in the United Kingdom for seven years, made the retroversion of ADT 2.0. This process only revealed an important difference in an issue that was, thus, adjusted.

This whole process of translation, analysis, and retroversion led to a first version of the AQ. It was decided from the outset to exclude some questions from the original ADT 2.0, related to the characterization of the respondent (part II of the ADT 2.0): these were not relevant for our respondents.

An expert in Science Teaching and Dissemination then analyzed this first version of the AQ (with part I – astronomy contentes – and part II – respondent characterization). This process resulted in minor format adjustments (namely, in the introductory text of the questionnaire and the creation of a comment space at the end of the AQ).

There was, at this point, a first stabilized version of the questionnaire that allowed us to proceed to the next phase: the pilot study, for instrument validation. This pilot study involved three participants. Although they were all elementary school teachers, like the future respondents of the questionnaire, they were chosen to cover different professional realities. The average time to complete the questionnaire was 10 minutes. The resulting changes were related to: i) typos correction; ii) clarification of the wording of the questions and of the alternative answers; iii) elimination of response options with the wording “more than one above”; iv) the place of the images in relation to the response options. In addition, the pilot study revealed that: i) teachers were curious about the solutions of the AQ and the explanation of the contents of the questionnaire; ii) it was necessary to know how to deal with questions where teachers had no idea how to answer (leave blank or answer randomly). This situation was the subject of profound analysis after which it was decided, if it arises when the questionnaire was being completed, no further instructions would be given (in line with Smyth, Dillman [31]) conclusions). Thus, when analyzing the results, it was assumed that the answers left blank were wrong (in this context, it is synonymous with lack of understanding of the concept).

Following this pilot study and with the changes that were made to the AQ the entire questionnaire was again analyzed by the aforementioned experts. Thus, we produced the final version of ADT 2.0 in Portuguese, which we now call the “Astronomy Questionnaire”. This renaming of the questionnaire was intended to remove the connotation, often understood as pejorative, that respondents were performing a diagnostic assessment. This title appeared already in the version for the pilot study.

2.1.2 Sample

AQ respondents had an average of 45 years old. Eight respondents were female and one male. Four teachers completed high school in urban areas, two in suburban areas and three in rural areas. However, at the time of the AQ testing five worked in suburban schools, three in urban schools and only one in a rural school. At the pretest, all teachers stated that they had never taken any specific astronomy course or participated in any astronomy initiative. For three of these teachers, it was CoAstro that provided the first contact with the Porto Planetarium - Ciência Viva Center (PP-CCV). These data, aligned with the means used for the dissemination of the project (social networks and email of teachers already subscribed to the PP-CCV mailling list) explain that most teachers (5 out of 9) were only aware of CoAstro by other colleagues.

2.1.3 Questionnaire implementation

The AQ pre-test was applied in the work package entitled “The CoAstro Presents” (December 2018) and took place at the facilities of the Porto Planetarium - Ciência Viva Center (PP-CCV). This work package of the project had, as its main goal, the presentation of CoAstro to the teachers. The completion of the AQ was the first task of the event. Thus, at the event secretariat, the questionnaire was delivered to be completed, inside the auditorium, while waiting for the event´s beginning. The information that the AQ was anonymous was provided. Therefore, after entering the auditorium and in the presence of CoAstro's mediator, the answers were given individually. Thus, 12 questionnaires were completed. Of these 12 teachers, nine confirmed, after the event “The CoAstro Presents”, that they wanted to proceed to the following CoAstro stages. The results of these nine questionnaires will be considered for analysis in the present paper.

After this pretest, CoAstro astronomers reviewed all the solutions for the questionnaire questions. This process resulted in the establishment of the final solution key.

The posttest was applied in the CoAstro's last work package (see section 1.1 of this paper): “D-Day at PP-CCV” (July 2019). This event, as the name implies, took place in the PP-CCV. It had, as main purpose, the presentation of the research developed by the teachers, to their school community. However, at a final moment of that day, the teachers completed the AQ individually, in the presence of the mediator.

3 RESULTS

The AQ results will be presented, first in this section and then triangulated with those collected by observation in other CoAstro work packages.

The results analyzes indicates that there was an increase in astronomy knowledge, from the pretest to the posttest. In the later, the dispersion of the results was greater (SD=16.4%), with a greater value of the result (42.9%). Only one teacher kept the same number of correct answers. For the remaining teachers this number increased in the posttest. The average percentage of improvement was 15.9%. Despite this overall improvement, confidence in responses only increased by 0.3 points (on a scale of zero to five). The AQ data are compiled in table 1.

Table 1. AQ pretest and posttest overall results.

	Pretest	***Posttest***	***Δ post-pré****
Teste average	20.6%	36.0%	10%
Standard Deviation (SD)	9.5%	16.4%	6.9%
Standard Error (SE)	3.17%	5.45%	2.28%
Maximum	42.9%	61.9%	19.0%
Minimum	9.5%	19.0%	9.5%
Average number of correct answers per teacher	4	8	4
Average number of wrong answers per teacher	17	13	-4
Average confidence in the answers (from zero to five)	2	2.3	0.3

* "Δ post-pré" corresponds to the variation between the posttest and the pretest.

Of higher relevance, than the item-by-item analysis, is a category analysis (table 2) that recovers those of the ADT 2.0 (on which the AQ was based): notion of scale, movements, gravity and general category.

This analysis reveals that in the pretest, on average, the percentage of correct answers in the "notion of scale" was 19.8%. This same average, in posttest, went up to 28.8%. Despite this improvement, teachers had difficulties to understand the scale of the Solar System and the scale of the Universe. There were also limitations in establishing relative distances between bodies in the Solar System and with those bodies and observable stars. It should be noted that the contents of this category require some capacity for mathematical reasoning. In addition, those contents were specifically worked in "One day at PP-CCV" (January 2019) work package but the posttest took place in July. In addition, not to be overlooked, is the systematic way that stars are represented, in infographics (namely, in elementary school textbooks), as the background of the Solar System. This leads to the idea that stars are positioned between the orbits of the planets.

In the seven questions of the "Movements" category, only 10 correct answers are counted (out of 63 possible), in pretest. In posttest, this value went up to 27. We highlight, positively, the issues related to the movement of the Sun and the phases of the Moon: themes that were worked in two CoAstro work packages. Here, it is important to note that the content "seasons" was also part of those CoAstro stages. However, most teachers, even in posttest, fail this question. This may be related to the formulation of the question: it appeals to an indirect correlation between rotational motion and translational motion – a reasoning only marginaly worked in one of the work packages.

In the gravity category, although there were two issues directly related to this content, they have different ranges, which resulted in different values (either pretest or posttest). The one that appeals directly to Galileo's experience (of the fall of bodies) and perhaps because it is not sensory on planet Earth, the results indicate that teachers do not understand the concept. Perhaps also due to the absence of this empirical experience, the sensation of weightlessness in orbit is not recognized. In the question where gravity is more easily related to the teacher's daily life, the concept is understood by the majority (six out of nine teachers).

The category of general physics and astronomy was, in the pretest, the one with the highest average of correct answers (27.7%). To this average, it mostly contributes the clear idea that the teachers already had about the indefinition of the center of the Universe. Nevertheless, this idea is reinforced in the posttest, where we had a positive average, also, in the perception of the origin of the Sun's energy. It is also worth mentioning a third topic that very clearly improves from prettest (zero correct answers) to posttest (four correct answers): the relationship between color and star's temperature. This result is even more significant because the solution of this question was determined only after an extensive reflection among CoAstro astronomers. This reveals the lack of simplicity of the theme. The topics of these three questions were, exactly, those that we worked more throughout CoAstro´s work packages. Once again, the questions that required some application of mathematical concepts (speed of light and the relation between luminosity and the inverse of the square of distance) were the ones that got the lowest rate of correct answers (either in pretest and in posttest).

Table 2. Comparative results, between pretest and posttest, sorted by conceptual category of the AQ.

Cetegory	Item	Δ of correct answers between post and pretest*
Notion of scale	3. Earth / Moon scale	11
	11. Earth / Moon / EEI scale	11
	12. Earth / Solar System / stars scale	22
	13. Object arrangement by distance	-11
	20. Angular distance	12
	Mean	9,0
Movements	1. Position of the Sun in the sky and shadows	22
	2. Eclipse and Moon phase	11
	7. Seasons and Earth’s orbit	33
	9. Change in the position of the Sun in the sky over time	56
	10. Position of the Sun and constellations in the sky	22
	18. Moon phases	0
	19. Moon phases and Moon motion in the sky	23
	Mean	23,9
Gravity	4. Gravity	-11
	6. Gravity and "weightlessness" in orbit	33
	14. Gravity	44
	Mean	18,7
Geral category	5. Electromagnetic radiation	-11
	8. Origin of Sun’s energy	11
	15. Light and inverse square relationship	0
	16. Location of the center of the Universe	11
	17. Star color and temperature	44
	21. Cause of global warming	11
	Mean	11,1

* “Δ” – variation

It is also noteworthy the fact that the number of unanswered questions decreased, from pretest to posttest. This may indicate that, rightly or wrongly, teachers, at least, would feel that they were able to justify their choice of response.

4 CONCLUSIONS

It was our intention, in the present paper, to analyze the evolution of substantial knowledge of key astronomy content, which can better be assessed with CoAstro, by measuring the relevance of a citizen science project (which combines remote interactions with systematic bilateral interactions) for a more holistic awareness and understanding of knowledge in Astronomy.

The AQ results demonstrate from pretest to posttest:

- a global increase in teachers' substantive knowledge of key astronomy content;
- an improvement in all conceptual categories of the questionnaire (“notion of scale”, “movements”, “gravity” and “general category”);

- more significant improvements in thematic categories (and within these in items) that have been worked on the CoAstro more extensively and over a longer time;
- less significant improvements in items that appealed to some (albeit rudimentary) mathematical reasoning;
- despite teachers, in posttest, indicate not having much greater certainty in their answers, they nevertheless state having an opinion about more of the items under consideration;
- the wrong answers, in posttest, have a different nature, from the initials, revealing a process of evolution to the scientific concept (they come closer to it).

On the other hand, when comparing to the results of ADT 2.0, applied in the USA and Turkey, we find that, although the different contexts in these countries when compared to the portuguese context (in terms of initial teacher trainning), CoAstro teachers in posttest score, as expected, below Demming´s respondents [27] – USA undergraduated students enrolled in introductory astronomy courses (CoAstro teachers 36.0% and Demming´s respondents 4.,3%). However, in posttest and after performing activities that allowed them to came closer to the profile of those respondents (at prettest), CoAstro´s teachers outperformed Demming´s respondents (32.4%). It should also be noted that CoAstro´s teachers outperformed their fellow Turkish [21] (34.2%) and North American [20] (35%) teachers.

Also noteworthy, and using only data from Brunsell and Marcks [20] (the other authors did not report this analysis), CoAstro´s teachers were, in pretest worse than their American counterparts, in 18 items. This value is, in posttest, 11.

These results reveal that a citizen science project, built on a model such as CoAstro's, supported by a collaborative view of citizen science and based on a PEST paradigm, can effectively contribute to the increase of substantial knowledge of key astronomy content. For this purpose, the key elements appear to be the involvement of teachers in astronomy research that will have motivated participants to undertake autonomous and, therefore, more meaningful and lasting learning.

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