Astronomy Education Research: Impact and Future Directions

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Abstract. The goal of this talk is to reflect about the achievements and challenges in Astronomy Education Research (AER). First, the answers given to questions asked of members of the IAU Division C's Commission 1 and Working Group on Theory and Methods in Astronomy Education are discussed. Next, the goals of astronomy teaching are discussed considering content, methods, levels, resources and purposes. Given the demands and complexity of education today and the role of astronomy in this context, the potential of education research is also evaluated, taking into account knowledge, practices, policies and the training of teachers. Finally, graduate studies are encouraged, new lines of research, and surveys to identify and advertise the dispersed AE literature seeking to raise the visibility of authors and institutions are suggested. Much of the work already performed remains unknown to astronomers, because they belong to a different area of theoretical and methodological framework, and because it occurs in specific different contexts of production, culture, curriculum, materials and application. Moreover, advertising AER in universities and schools to professors and teachers should consolidate this community and establish links between astronomers and educators in general, allowing future collaborations.

1. Introduction

We start the discussion on Astronomy Education Research (AER) with two questions asked by e-mail on May 1st of 2017 of members of the IAU Division C's Commission 1: Astronomy Education and Development and its Working Group on Theory and Methods in Astronomy Education. The questions were:

1) What are the achievements and impacts of AER in the last decades?
2) What are the objectives and challenges of AER for the next decades?

We received 16 very good answers before 16 May and I would like to thank my colleagues for their collaboration. The answers were analyzed and are discussed here, together with my own reflections on these subjects.

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2. Achievements and impacts of AER in the last decades

The achievements and impacts of AER mentioned in the last decades were: effective techniques for teaching astronomy; construction of a variety of concept knowledge inventories; strategies for alternative conceptions assessment and development of classroom techniques to overcome them; development and evaluation of active learning; creation of journals; publications of theses dissertations, conference proceedings and journal articles.

Regarding **effective techniques for teaching astronomy**, many didactic materials and techniques for teaching astronomy were developed through the years. Some longitudinal studies looking at student attitudes and achievements were made. Particularly in the U.S., effective techniques were studied for teaching Astronomy 101, a college course for non-science majors which seems to be a U.S. institution although less common around the world.

Many publications on the **construction of a variety of concept knowledge inventories** exist. Many of them are well-known, such as children's understanding about day and night and phases of the Moon (Baxter 1989 and 1998), Nussbaum's (1979) on the Earth, Camino (1995) and Barrabin (1995) on the seasons. Surveys about misconceptions such as Lightman and Sadler (1993), Zeilik, Schau and Mattern (1998), and Trumper (2001) exist, and many other papers.

Strategies for alternative conceptual assessment, and development of classroom techniques to overcome them, have prompted many studies in the last decades. However, these studies dealt only with Methodologies and Didactic Materials; a wider range of studies is preferable. Techniques to teach seasons with balls, computers, and software are available, as well as the relative sizes of Sun, Solar System, Stars, even using portable planetariums. We can see many misconceptions in this picture of models (Figure 1), as the relative sizes and distances in it are not correct. Better techniques and resources to calculate sizes and distances exist (Figure 2).

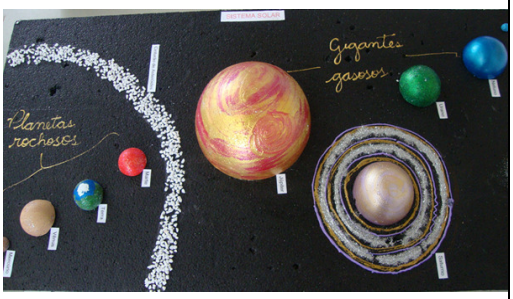

Figure 1 - Solar System out of scale

Figure 2 - Solar System at scale

Apparently, the "old" astronomy of learning numbers and positions is not enough. For example, the familiar Sun-Earth-Moon system is often taught in terms of scaling, rather than in absolute terms. But scaling is not enough, either. For example, what do the relative scales mean for astrobiology? How can the subject be linked to a lesson in Physics, Chemistry, or Biology without using the absolute numbers rather than ratios? But there are many good projects on astronomy education even in many countries of the world and many of these have been created by familiar IAU projects. Some of them are GHOU (Global

Hands-On Universe) GTTP (Galileo Teacher Training Program), OAD (Office of Astronomy for Development), OAO (Office for Astronomy Outreach), Astro EDU, Universe Awareness, Astronomers Without Borders, Network for Astronomy School Education (NASE), Division C's WG Astronomy for Equity and Inclusion etc.]

Development and evaluation of active learning is defined as "… a process whereby students engage in activities, such as reading, writing, discussion, or problem-solving that promote analysis, synthesis, and evaluation of class content" (Center for Research on Learning and Teaching at the University of Michigan, 2017, http://www.crlt.umich.edu/tstrategies/tsal). There are publications, such as books (Zeilik, 2002; De Jong, 2005) and projects about active learning.

On the **creation of journals**, in the last years some publications dealing specifically with Astronomy Education have been launched. The creation and unfortunately now ceased publication of Astronomy Education Review (AER), which published 19 issues featuring 255 articles between 2001 and 2013 (Fraknoi, 2014) is an outstanding example. Teaching of Astronomy in Asian-Pacific Region (TAAPR), edited by Prof. Isobe, is another unfortunate case. TAAPR published 20 issues featuring 171 articles in English between 1990 and 2003. We are in contact with colleagues from Japan because, until now, only printed editions have been available and this material should be shared electronically. It is clear from cases like this that a literature review in the area is needed, to share what has been published up to now.

We have participated in the launching of the Latin-American Journal of Astronomy Education (RELEA). More than 100 papers have appeared so far, albeit with an average of only five papers per edition. RELEA articles are indexed by the ADS and Google, but not Scopus because of their requirements. Some important numbers about RELEA are: acceptance rate (60.2%), annual average (7.5 papers) and issue average (4.2 papers) (Bretones, Jafelice and Horvath, 2016).

Recently the Journal of Astronomy & Earth Sciences Education (JAESE), which includes articles on astronomy as well as related areas, has appeared in the USA, and is edited by Tim Slater and colleagues. There have been 25 papers published in JAESE since 2014.

Other relevant publications of astronomy, such as Communicating Astronomy with the Public (CAP), have good papers published on practice and research. Universe in the Classroom (since 1984) and the Newsletter of Commission CC1, published initially as Com 46 (since 1977) are additional examples. One of the current projects of the WG on Theory and Methods is to obtain the PDF versions of the first issues, by asking colleagues and searching in libraries. The same applies to Gnomon, published by the AAE (Association for Astronomy Education) in the UK, but obtained no PDF versions and we have ceased looking. Other cases are The Classroom Astronomer (2009 to 2015) and the Journal and Review of Astronomy Education and Outreach (2014 to 2015), which lasted only 2 years and had 3 editions. The Journal "Astronomy Education" of the Japanese Society for Education and Popularization of Astronomy has been published since 1989. Through July 2016 it published about 1544 papers, but only in Japanese. This is very good for the community in Japan, and we would like to have a translation available.

Concerning **journal articles**, as Tony Lelliott discussed earlier in this meeting (Lelliot, 2017), he has made a literature review of papers in journals of science education.

Besides the journals, **conference proceedings** contain a fraction of the whole. Proceedings of IAU meetings have consistently contained papers on the subject, although those did not go deeply into the questions and problems of education. A paper with an analysis of such proceedings has been published (Bretones and Megid Neto, 2011). Our paper analyzed about 300 papers and was published in Astronomy Education Review. It is a first effort but serves to demonstrate the methodology of how to analyze the proceedings

of IAU meetings. In that example we have analyzed year, author, institution, school level, focus of research on education and type of academic research. That work analyzed the contributions at IAU meeting from 1988 to 2006. However, there are many other IAU meetings to be analyzed, for example those held in Rio, Beijing, and Hawaii.

For the Proceedings of Symposia on Teaching Astronomy COSMOS IN THE CLASSROOM, published from 1998 to 2013, there are only printed editions. We have no PDF versions, but studies on trends and gaps could be done. In Europe, the International Conferences on Teaching Astronomy had the great contribution of Rosa Ros as the editor of many of these Proceedings, but again only printed versions exist.

The European Association for Astronomy Education Summer Schools is in the latter group. From the 1997 edition held in Spain to the 2010 held in Germany, a lot of the material was published with suitable companion didactic supplements. The Annual Meeting of the Brazilian Astronomical Society (SAB) featured an increase in the number of papers related to AE, possibly because of the creation of the Commission of Education of the SAB in 1993. There are many other papers published in Science Education meetings still to be found.

Concerning **publications of theses dissertations,** in the USA there are about 500 published (Slater et al, 2016). In Brazil, even if not high in the overall ranking of education, we had an increase of AE in the last few years because of the support of financial agencies for Science Education. We have a data bank with currently about 170 works, which are now available on the Internet at http://www.btdea.ufscar.br/. Recently, we have published a work based on a first survey about MSc Thesis published in Colombia (Bretones and Camino, 2017). There we found only 13 works, but this is one of the ways to help a community to recognize themselves.

Summary reviews feature some important examples: Wall (1973); Bailey, Prather, and Slater (2004); Bailey and Slater (2004); and Slater (2008). Lelliot and Rollnick (2010) examined 103 peer-reviewed journal articles and discussed the Big Ideas: Earth, gravity, the day–night cycle, the seasons, and the Earth–Sun–Moon system, as well as stars, the solar system, and the concepts of size and distance. The authors recommended that future research should work across the disciplinary boundaries of astronomy education at both school and teacher education levels, and aim to disseminate findings more effectively within the education systems.

Other regions such as Africa, Middle East and Oceania have their own scholarly works and studies, although scarce in number. One of these few studies is Broadfoot and Ginns (2005), who made a study of the works produced in Australia.

All works and publications need to be surveyed, and the papers made available. One recent effort by Slater et al. (2016) with the iSTAR Database is underway, but extensive work to get the works of many countries of the world remains, with the local language being a primary factor to overcome.

3. Objectives and challenges of AER for the next decade

Among the objectives and challenges of AER for the next decades, our colleagues mentioned: consolidating the achievements; deeper treatments dealing with epistemological questions; increasing the methodological rigor; development of models to connect new technologies in a variety of contexts and instruments to probe student attitudes; astronomy to improve science education and to link other branches of culture; investigate the roots of astronomy in each nation and respect multiculturalism.

To **consolidate the achievements**, there are many subjects that need further research, even with different school levels and contexts.

Deeper treatments dealing with epistemological questions: Nicoletta Lanciano lectured in this meeting about different Education Approaches (Multi, Intra, Interdisciplinary). We should nevertheless remember that when dealing with each one of these areas, physics, chemistry, biology etc., many times it is a multidisciplinary approach that is involved. However, we make links in the brain or mind when we solve problems with different epistemologies, thus it is not just dealing with the content. It is also how we handle each subject when we are solving problems in different ways. One of the examples was related to Apollo 13. Do you remember the problem with CO_2? This is an example of a different epistemology to solve problems, in different questions and ways. It is the same in Astrobiology. This approach could be very well applied to many different situations in education.

The need to **increase the methodological rigor** is quite a challenge, since we have a community that is very heterogeneous, including not only astronomers and astrophysicists but cosmologists, biologists, chemists, and many others. The astrobiology groups are interdisciplinary, and feature different people working together. Many times, there is some rigor because of the use of methods common to the hard sciences, which is not the same of education. The latter, for instance, uses a qualitative approach, which is absolutely necessary and amenable to working with different methodologies. This is one of the things that we see as editors when we organize a meeting: papers with a big introduction, results, and no discussion at all, that is, a bad paper. The submission of papers from undergraduate students starting science education projects falls within this category.

Concerning the **development of models to connect new technologies in a variety of contexts**, there are a lot of resources to be developed but we also need to address the access of new technologies in different contexts. In this category, we have didactic models about the celestial sphere and related ideas in software, which are very useful even with the planetarium (Bedaque and Bretones, 2016, Figure 4).

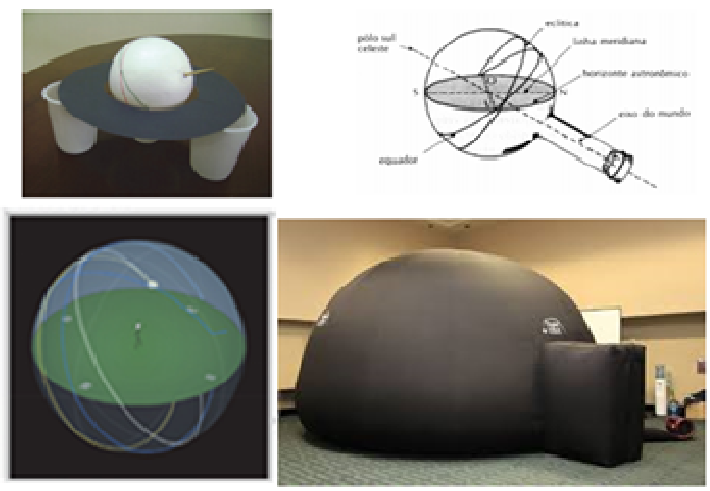

Figure 4 - Models about celestial sphere

Figure 5 - The Sky in Your Hands

Other examples are the resources produced by the IAU WG Equity and Inclusion as seen in Figure 5. The Sky in Your Hands is a planetarium show specially designed for blind and visually impaired people.

About **instruments to probe student attitudes**, we can ask: How can we observe and collect evidence of student attitudes? The first one is to begin using the familiar Likert

scale. But how to probe deeper in these questions? What do the people or students do in their real lives? For instance, we have students learning in a classroom, but they might also have activities within a group in their community. How can we probe this? How can we get information about attitude? One of the possibilities is to ask for reports from one class to other. This subject is relatively new in education and must be developed.

The goal of using **astronomy to improve science education and to make links with other branches of culture** calls for much more than observations of the sky: it is important to get reports from the students and to bring in more about culture and arts, connecting these subjects with the science contents.

To **investigate the roots of astronomy in each nation and with respect to multiculturalism**, it is important not only to bring to the students and teachers new knowledge on astronomy, but also to know local traditions. That is, trying not to put too much western science before local views, as exemplified by many projects of colleagues in Africa. And more importantly, how should these studies be used in the formation of students and teachers?

4. The projects of the WG on Theory and Methods in Astronomy Education

In our WG, we recently set up a web page at http://www.iau-wgtm.ufscar.br. The primary goals are:

1) Develop a promotional strategy for enhancing Astronomical Educational Research (AER);
2) Promote, in different regions and continents, literature reviews, summary reviews of scholarly works that already exist in PhD and MSc theses, proceedings of meetings, and published papers in Journals on Physics and Science Education;
3) How to teach astronomy at different levels;
4) Promote structures and very successful practices such as GHOU, GTTP, NASE, UNAWE etc.;
5) Promote meetings, journals and courses in regions and continents to enhance AER.

However, the most important issue for us currently is #2, the literature reviews of the scholarly works. There is a recent report about our own activities from Aug 2015 to Oct 2016, (Bretones et al 2016) available online. Table 1 shows a summary of the received surveys and results from colleagues of some countries. We are pleased to see this initiative growing.

Table 1. Received Surveys and results of the WG on Theory and Methods in Astronomy Education

Contact/Country	**Surveyed Country**	**Results**
Néstor Camino/Argentina	Colombia	8 MSc thesis; 28 undergraduate theses
Urban Eriksson/Sweden	European Countries	12 contacts of researchers and works
Paulo Maurício/Portugal	Portugal	51 MSc thesis; 2 PhD thesis
Frederic Pitout/France	France	7 PhD thesis; 31 papers; 2 works
Nicoletta Lanciano/Italy	Italy	4 PhD thesis; 17 *Laurea* Thesis; 63 papers; 53 works
Aniket Sule/India	India	11 contacts of researchers and works 11 papers; 8 works
Akihiko Tomita/Japan	Japan	1544 papers

Examples of some remarkable questions and the difficulties in finding researchers and papers published in many languages and countries are:

> In this paper, we discuss significances to organize our studies about astronomy educations and out-reach activities in (academic, peer-reviewed) papers. We research the trend of recent (peer-reviewed) papers about astronomy education, and we show that the papers are severely dispersed. For the establishment of astronomical education field as an important branch of academic discipline, broad sharing of knowledge in this field is highly required. (Agata, Karino, and Matsumoto, 2015).

> (…) I have used many different channels to identify European AER persons, and I continue to do so, and I send you the short (!) list I have so far. . . It seems to be very few, but I guess there are more AERs in different countries. I have learned that language difficulty is a large barrier and AER persons often only publish in their own language and countries. This makes it increasingly difficult to find them. (Eriksson, 2016)

Despite an obvious language barrier, it must be acknowledged that these publications have made an improvement for the people of their country, and not all the material is suitable for everybody else. However, availability of this "hidden" material is a long-term goal to be achieved.

5. The goals of astronomy teaching and some questions about education today

To move forward I think that it is necessary to reflect about the goals of astronomy teaching. There is more than content, resources, methods, and levels: it is important to consider the purposes as well. Among them we may mention: Is the formation or learning of students necessary for their work or for their personal growth? Is it more important to work on the concentration or for the multiplicity of stimulation? Should the priority be the local culture or the globalized world? Is it more important to stimulate the individual to make decisions, or the collaboration of groups? Given the demands and complexity of education today, what is the actual role of astronomy in this context? The evaluation of the potential of education research must also consider knowledge, practices, policies, and training of teachers.

I will give a concrete example. Astronomers had taken part in discussions to reform the curriculum in Brazil, but other sciences had different views. What is the best way to teach these subjects for each of the school levels? What does it mean, for example, to include cosmology or modern physics for children? How can we do this? It is quite necessary, beautiful, and interesting to teach, but how do we do it in practice? It is quite a challenge.

But there are also questions about Astronomy Education Research (AER). AER faces the same challenges as many other disciplines. There is a lack of positions for professors and educators, little time for astronomers to work on AER, lack of financial support and training, insufficient research about public understanding, and many other issues. The outreach of science education programs of great observatories, space agencies and big projects do not generally consider doing AER.

It is quite clear that more journals and publications, publication of papers containing theses material, and proceedings of meetings (at least abstracts!) are needed. For many meetings in which I have participated, not even abstracts are made available by the SOC

(Science Organizing Committee). Well, if there were accepted papers to be presented, why not get at least the abstracts and publish them? I hope that this situation is now over.

Another problem I can see is a lack of awards in this field, as happens in many other areas of astronomy. As a social contribution, teachers and educators should be eligible for awards related to their scholarly work in AER.

When we talk about AER there are different interpretations, many of them conflicting, of the work: research vs. teaching, astronomy vs. education, content vs. method, thinking vs. doing, studies vs. services, discovery vs. known. We need to talk about a useful mix of these things to shape research in education.

AER may have several applications and motivations: the personal interest of researchers to obtain knowledge, enhancing their practice, career advancement, and advancement in this field of knowledge. So, it is important to consider these different origins and purposes of the researchers.

How best to investigate the "output publications": PhD and MSc theses; proceedings of meetings; journal papers? These works can be classified by country, institution, grade level, topic/content, -focus of study in education, type of academic research, and theoretical framework. Another set of classifications might be the focus of study in education, curricular discussions, and programs, learning and teaching, teaching materials, student understanding, teacher understanding, concept development, teacher education, non-school programs, history and philosophy of science, history of astronomy education, and review of academic research. Or one could consider the types of academic research there are: case studies, action research, experimental, etc.

We believe that there is already sufficient production of scholarly work, and surveys will reveal much “hidden” material that may be available locally and internationally. Much of the work is certainly not known by researchers in astronomy, because it belongs to a different area of theoretical and methodological framework (Education). Studies may be related to teaching in physics and the general sciences, rather than Astronomy specifically, or they may be studies made in different contexts of culture, curriculum, materials and application, and many other reasons.

Therefore, we encourage colleagues to make surveys of the AER literature and identify, review, and advertise the dispersed AER literature to raise the visibility of authors and institutions. We are asking for collaboration in the process: Surveys → Get publications →Digitize → Get Files → Internet → Studies. These actions are important to enable studies showing trends and gaps, thus allowing for future developments.

Finally, graduate studies and programs are encouraged. We need new lines of research for different content areas (e.g. Galaxies), data acquisition, theoretical and methodological framework, sampling, and contexts. Here are two examples of my own MSc students:

1) Considering the phases of the Moon, in the literature only 15% of the papers recommend that children observe the sky. What do you think about this? To begin the model inside of a room and not suggest that the children go outside to observe? The following work considers this practice with children: ‘Astronomy at the elementary school level emphasizing observations of the Moon’: Paula Simon, 2016.
2) Considering astronomy as a vehicle for promoting reflections about the human condition, you have probably heard the Carl Sagan talk or video about “the pale blue dot”. At the last IAU GA (General Assembly) many colleagues discussed the lack of these kinds of studies for students. Carlos Nascimento, an MSc student, has worked with astronomy content and philosophical reflection on astronomy with high school students. He started with observations of the sky and the Blue Dot video, and then continued with astronomy and philosophy content. The students discussed questions such as "who are we?”, “where do we come from?", “what is the origin of all things?" and other related questions. This work is the basis of the Master’s thesis: ‘The

construction of human smallness concepts: astronomy in high school philosophy classes' (Nascimento, 2017).

What about the education of the AER researcher? Is more astronomy or more education better? These are different communities, which remain unfortunately separated. In many talks with colleagues at graduation, they tell me: "I only have the MSc degree. I did not finish my PhD. So when will I be an AER researcher? Did you get your degree in education? How many years did it take?" It depends on each case, but the learning of content in astronomy never ends. It is a continuous process. AER features a lack of social science researchers, and there is a necessary interface with Philosophy, Sociology, Psychology, History etc. There are interesting things to be done and bridges to be constructed.

We do believe that it is important to encourage publications in journals of regional and international circulation; this advertises AER in universities and schools to professors and teachers, and creates an agenda for future meetings. It should consolidate this community and establish links between astronomers and educators, thus allowing future collaborations. Concerning research and teacher training, the **'**Teacher as researcher' is well known in education from the works of Lawrence Stenhouse (1975), John Elliot (1988), and others. Also known is the model of 'Reflective teacher' in the works of Donald Schön (1987) and others. And consider the citation of Paulo Freire (1996), from Brazil: "There is no teaching without research and no research without teaching".

The Bologna Process (Crosier and Parveva, 2013) recommends the following for the teacher formation: 1st cycle is a bachelor's degree, 3-4 years; 2nd cycle is a master's degree, 1.5-2 years; 3rd cycle is a doctoral degree, varying times. In this way, it is possible to form teachers who are also researchers. To finish this discussion of astronomy education research, we note that it is important to recognize the difference between providing services (action) and studying (research). It is important to the teachers to not only do, but to think and reflect.

Reflecting about the required classes, we could ask the teachers, professors, educators, and ourselves: What are you doing? Is it important to do? How can we do different things? What do you think about you are doing in the classroom? Or many other questions. This is something important from my point of view, and it is my contribution.

I would like to thank the organizers of the meeting here in Netherlands...Dank u wel!

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