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RESEARCH REVIEW

A descriptive overview of English-language publications in the field of Astronomy Education Research, 1898 to 2022

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Abstract

Discipline-based education research (DBER) takes the theories and methodologies of education research and applies them in the context of a specific discipline, in this example, astronomy. Research in the teaching and learning of astronomy has an extensive history; astronomy education research (AER), as its own separately defined field, is relatively new, stemming from the early to mid-1990s, as a separate track from physics education research (PER). By using a mixed-methods approach to textual analysis considering 2085 English language publications in the field, an order of magnitude larger than the previous largest overviews of the field, this study paints a rich picture of the landscape of AER over the timespan of a century from 1898 to 2022.

This paper finds that AER authors started regularly publishing around 1970 and took off significantly in the 1990s with journal articles (~50%) and conference proceedings (~30%) being the most common method of publication. AER, in its early era, was largely a USA endeavour dominated by ASTRO101. This has changed over time and in recent years, the USA has dropped below 50% of the worldwide AER publication production. “Celestial Motion”, “Instrumentation/Techniques”, and “Planetary Sciences (not Exoplanets)” are the most common content foci while a significant lack of local galactic and extragalactic education research is identified. AER has been heavily focussed on “Content Knowledge”, “Affective”, and “Engagement”. It is found that most articles tend to be general reporting of approaches or results (~43%) rather than full empirical research (~36%) while there is very little theoretical or historical research in AER yet.

This overview, based on results input to an online database (istardb.org), provides a resource to researchers, educators, and other interested stakeholders allowing efficient ascertainment of previous research. This supports both researchers, allowing them to develop research questions at the cutting edge of the field, as well as practitioners, to inform their pragmatic approach based on latest research findings. We also present a set of recommendations and future outlook of the field of Astronomy Education Research.

Keywords: Astronomy Education Research, Research Review, Systematic Analysis, Literature Search

1 Introduction

Astronomy is often labelled as being the oldest science (North, 2008), and in early cultures across Europe and the Middle East stemming from the time of Plato, astronomy was part of the Quadrivium, together with arithmetic, music, and geometry (Salimpour, 2021). Over the years, it has enjoyed varying degrees of presence in the curricula of schools. Research has shown that across the Organisation for Economic Co-operation and Development (OECD) countries, China and South Africa, topics in astronomy are present in some form, especially in the primary and middle years (ages 6-15) (Salimpour et al., 2020). The focus is mainly on topics concerning Celestial Motion and the Solar System with some distinct gaps in the curriculum (Salimpour et al., 2024) compared to what is expected of a literate person in astronomy (Retrê et al., 2019).

It has also played a significant role in general science requirements for undergraduate education in the United States as "ASTRO101". ASTRO101 or Astronomy 101, is an introductory astronomy subject that can be taken by any undergraduate students at Universities (particularly in the United States) as a way to fulfil the general science requirement. Students taking ASTRO101 may not necessarily have a prior exposure science and/or do not plan to pursue science at University (e.g., Brogt and Draeger, 2015; Deming and Hufnagel, 2001; Rudolph et al., 2010).

Astronomy, despite being universal and awe-inspiring, encompasses some very complex and counter-intuitive spatial and temporal relations. This is perhaps the most challenging characteristic when it comes to the teaching and learning of astronomy (Comins, 2001; Schneps and Sadler, 1987) and even university students may struggle to understand these aspects of astronomy (Eriksson and Hellgren, 2023; Euler et al., 2022). Although education research more broadly has tackled the teaching and learning of concepts in astronomy, the field of astronomy education research is relatively young and unexplored.

1.1 Curriculum, Scientific Literacy and Big Ideas

In this overview, we will utilise the terms "curriculum", "scientific literacy" and "Big Ideas" to categorise and explore the distribution and relation between research papers. Education research differs from basic science or social science research in that it has stronger links to actual educational practice than just learning how learning works. Hence links between education research and the activities, contexts and goals of the practitioners are much more important to consider than most other research fields aside from, perhaps, medical research. Here we introduce and consider these links through the various educational goals defined by curriculum and scientific literacy.

The notion of a formalised curriculum has for over a century become a vital part of education systems (e.g., Bobbitt, 1918, 1924). In its simplest form curriculum means "course of race". According to Bobbit, the curriculum is designed to give educators a set of procedures enabling students to attain certain objectives, this is perhaps one of the key features of curricula around the world. One thing to emphasise is that the notion of curriculum is not simply "the curriculum", rather it has different manifestations – imagined, mandated, and enacted (implemented). The imagined curriculum is what curriculum developers hope the curriculum will achieve, the mandated curriculum is what is legally supposed to be taught by teachers, while the enacted (implemented) curriculum is what is actually taught in the reality of the classroom. Curriculum in the context of this research is essentially the mandated curriculum.

One of the aims of the curriculum is to support students in developing the required literacy of the subject. In the case of science, it is about developing student's scientific literacy, which is more than the mere facts of science (e.g., DeBoer, 2000; Roth and Lee, 2002). Scientific literacy is developing student's "ability to make decisions related to the technological applications of scientific ideas or socio-scientific issues facing society" (Holbrook and Rannikmae, 2009, p.279).

In an effort to inform curriculum and policy development a concerted effort by the astronomy and astronomy education communities resulted in the development and publication of the "Big Ideas in Astronomy: A Proposed Definition of Astronomy Literacy" document (henceforth Big Ideas) (Retrê et al., 2019). This document was created by astronomical research scientists, albeit those with an interest in education, and astronomy education researchers/practitioners in a working group of the International Astronomical Union - Commission C1 Working Group Literacy and Curriculum Development. The sources of such "Big Ideas" documents traces back to the AAAS Project 2061 (AAAS, 1986) and has been developed for other fields such as Climate Science Literacy (United States Global Change Research Program, 2009), Earth Science Literacy Principles (Wysession et al., 2012), Ocean Literacy (Ocean Project, 2005) and Big Ideas of Science (Harlen et al., 2010).

The Big Ideas document contains 11 Big Ideas, each with a set of sub-ideas, which together make up 97 concepts in astronomy. These concepts are essentially a consensus view by the astronomy and astronomy education communities of what a science-informed or rather scientifically literate 21st century citizen should know about astronomy. The Big Ideas are more than mere content statements but bring together the various dimensions of a concepts. It should be emphasised that the Big Ideas are not curriculum statements, rather they are designed to help inform curriculum development. When we refer to the "Big Ideas" in this paper we are referring specifically to the idea and categories coming from this document. We note this specifically because the previous (Lelliott and Rollnick, 2010) review used "Big Ideas" in a different manner and "big ideas" is also a term used in learning progression research (e.g., Plummer and Krajcik, 2010; Schuster et al., 2018) of which there are a number of high-quality AER examples emerging over the last decade (e.g., Plummer and Maynard, 2014).

1.2 Motivation

Part of the motivation for this article was the perception of the authors that there was a lot of "reinventing wheels" in certain topics whereas other seemingly significant topics had largely been left unstudied. Sadler (2004) points out that while research scientists are attuned to looking at previous studies of scientific phenomena to inform their own research, in contrast, educational efforts are commonly begun without attending significantly to prior research. The excitement of implementing the project "propel it prematurely into production mode, eager for a prototype or field test" *(ibid).*

It is this recommendation that building education research into Education and Public Outreach projects sets goals and provides rigour to the effort. Furthermore, the last overview of astronomy education research by Lelliot & Rollnick (2010), covered 35 years from 1974 to 2008. The aim of this current work was to determine how the landscape of Astronomy Education Research (AER) has changed since and to extend the timeline further back in time. In fact, we aim to cover all AER that has been published in English. In so doing, we provide an overview of 2085 individual pieces of research from 1898 to 2022. There are broader motivations for such an overview and what it can enable that have been discussed in detail in prior overviews. These include:

- To understand the academic production of the field and what would be classed as "state-of-the-art research" (Bretones and Megid Neto, 2011).
- To expand knowledge in the field to include broader areas beyond AER such as cognitive science or educational psychology (Bailey, 2011) - "If we do not, we will remain in the shadows of research, doomed to repeat other work in an amateur fashion" (p.36).
- To facilitate moving beyond superficial knowledge and work more toward understanding the underlying cognitive mechanisms ((Bailey, 2011).
- Issues arising from the heterogeneity of practitioners of AER compared to the relative homogeneity of professional astronomers (Slater et al., 2015b), particularly those relating to knowledge transfer across different communities of researchers leading to domination of a small, usually privileged, group of voices, settings, frameworks, methodologies and geographies (Slater et al., 2016) to the detriment of both privileged and non-privileged.
- Being able to focus attention on more diverse areas of research that can help to drive outcomes in student learning (Slater et al., 2016).
- To facilitate the setting of an agenda for future AER (Lelliott and Rollnick, 2010).
- To describe the methodologies and theoretical frameworks used in the field (Lelliott and Rollnick, 2010).
- To understand to what degree AER has furthered our understanding of astronomy teaching and learning (Lelliott and Rollnick, 2010).

Therefore, and to complement the above, we here attempt to give a complete overview of the field. We do need to provide, at this stage, a note on terminology. Most of the previous articles summarising the literature utilise the terminology "review" in one way or another. The word "review", just by itself, is an overloaded term. Is it a 'systematic review' that follows the PRISMA guidelines (PRISMA Statement, 2020) Is it a 'scoping review' (Arksey and O'Malley, 2005) that attempts to ascertain the quality of the research considered? There are quite a number of different types of review and their definitions can drift between different research domains. For this article, we use the terminology "descriptive overview".

An "overview" generally refers to a systematic review of systematic reviews (or a meta-analysis of meta-analyses) but is actually exceedingly rare in education (Polanin et al., 2017). In the absence of a true "systematic review" of any topic directly in astronomy education, we append the term "descriptive" to refer to the fact that we are not answering any causal hypothesis or commenting on the quality of studies nor their relative effect sizes but just directly presenting the description or map of the field.

1.3 Research aim

This paper thus aims to provide a descriptive overview of the landscape of AER covering 2085 individual pieces of research over a period between 1898 - 2022. This is captured by the overarching research question:

- What is the landscape of AER literature between 1898 - 2022?

In doing so, this paper tackles various finer-grained lines of inquiry, such as:

- How has the landscape of AER changed over time?
- What, if any, topics in AER have had significant numbers of publications? And; what topics have relatively small numbers of publications?
- To what extent does the research align with what is generally present the mandated curricula and suggested for scientific literacy?
- What is the general distribution of constructs used in AER?
- What is the general distribution of methodologies?

2 Methodology

This overview employs a mixed-methods approach (Robson and McCartan, 2016; Tashakkori and Teddlie, 2010), in the context of textual analysis (McKee, 2003). In this paper, the questions are very broad attempting to categorise the nature of the entire research field itself over time as a basis to support further research. It is mixed-methods in the sense that both qualitative and quantitative methods are used to analyse and represent the findings in the article.

Although there is a rich diversity in research being published in languages other than English, journals ranked in Scopus only cover English language publications. This is perhaps something that may change over time; however, articles published in some non-English journals, like the Latin American Journal of Astronomy Education (RELEA) (Bretones et al., 2016), allow authors to submit an English abstract. This approach has been adopted by the new international Astronomy Education Journal (Eriksson and Bretones, 2021) (`https://www.astroedjournal.org`), where authors can submit an abstract in their native language, to accompany the manuscript. Therefore, this study focussed primarily on English language articles.

2.1 The literature search

The important goal of undertaking a literature review of prior literature before embarking on research is hampered by the capacity to find such literature. One of the common complaints heard by people new to the field is that the research is hard to find. This is a byproduct of there being no central set of journals purely focussed on AER with most articles being spread across a range of science, STEM and education journals and conference proceedings. There have, to date of publication, only been four journals that have specifically focussed on AER. These are; the Astronomy Education Review (2001 – 2013) (Fraknoi and Wolff, 2001) , RELEA (2007-current) (Bretones et al., 2016), the Journal of Astronomy & Earth Sciences Education (JAESE) (2014 - current) (Slater, 2014), and the Astronomy Education Journal (AEJ) (2019 - current) (Eriksson and Bretones, 2021). The full process of identifying and assessing publications is summarised in Figure 1 and described in more detail below.

2.1.1 Identifying publications

The first step involved a systematic literature search through various databases and journals to search for papers, proceedings, books and theses (both Masters and PhD) focussing on astronomy education. There have been previous attempts to provide overviews of various aspects of AER. This has primarily been through publications of overview articles summarising certain slices through the literature at given times. Drawing on, and extending, the summary provided in Slater et al. (2016) , we

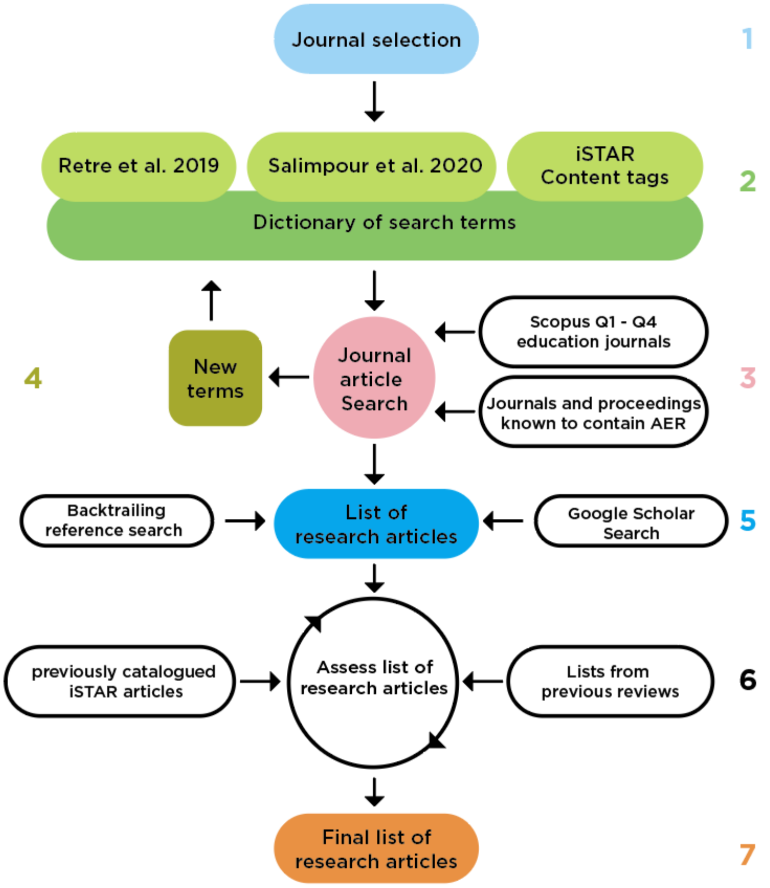

Figure 1. A schematic of the literature search process described in the text.

provide a summary of these attempts, shown in Table 1. We note that we do not include the highly detailed deep-dive on the development of the AER field undertaken by Bailey (2011) as an extension of her 2003 article as it was not specifically focussed on summarising the statistics of publications. It does, however, provide excellent context for the 'third era' of AER - the rise from the early 1990s to the mid-2000s and the "first big wave of astronomy education research dissertations" as noted in the title of the paper by Slater (2008).

The literature search process involved first creating a dictionary of terms to use as search terms. These terms were curated using the experience of the authors as astronomers and educators, previous iSTAR categories (Slater et al., 2016), curriculum statements (Salimpour et al., 2020), and the Big Ideas in Astronomy document (Retrê et al., 2019). The list of keywords used are provided in Table. 2.

Next a list of journals to search through was created by using Scopus to find all journals in the discipline areas of astronomy and education. Each issue of the journals was searched using the search terms, and articles were collated. As Scopus does not list all known journals and no conference proceedings, we also searched through other reputable journals and conference proceedings series known to have previously contained AER.

Conference proceedings and journal articles are relatively easy to identify. Generally, they are all catalogued in Google Scholar at the very least, generally exist in a series extended over time and commonly have their own searchable websites and publication archives. Books and Theses are different. Books can be found on Google Scholar but not all of the time and older, or out-of-print, books are much less likely to be catalogued this way. These are even harder. Sometimes they are only presented on a university website and if the author has not shared it on another publication archive that is scraped by Google Scholar, it can go unnoticed. However, we undertook an approach to identify these more difficult to spot publications through Google Scholar searches on the search terms and through the reference trail search.

The reference trail search was also manually undertaken by inspection of reference lists for publications that were collated to ensure that articles not captured by the search terms or the journals that were not selected in the initial search were found. It should be noted that although our search was limited to English language journals, we did look at non-English journals as a result of the reference trail search.

2.1.2 *Selection criteria*

Once the list of publications was complete, an assessment was made as to determine whether a publication was AER or not. There is potential overlap between two nearby fields of research. For instance, when is an article an AER paper and when is it a Physics Education Research (PER) paper? There is some degree of overlap at the edges of each discipline which leads to interesting borderline cases, such as topics of spacetime, relativity, particles. It could be said that general relativity and spacetime are inextricably linked to cosmological concepts and phenomena. However, the argument can be made that spacetime just on its own is purely a physics content knowledge topic, whereas something like gravitational waves (Abbott et al., 2016), which uses physics spacetime concepts, is an astronomical content knowledge phenomenon as it deals largely (at this stage) with collisions of astronomical objects at cosmological distances. Having said this, most articles were easily categorised as AER or not.

Table 1. A snapshot of previous work done in synthesising AER efforts.

Author	Year	Content Scope	Geographic Scope	Document Types	Analysis Method	Number of papers
Wall	(1973)	All	International	Theses & Dissertations	Annotated Bibliography	58
Bailey & Slater	(2004)	All	International	Peer-reviewed Work & Sadler's Dissertation	Annotated Bibliography	<100
Fraknoi	(2007)	All	International	Peer-reviewed Work in AER journal	Descriptive Statistics	roughly 100
Brazell	(2009)	Planetarium	USA	Peer reviewed, Dissertations	Quantitative Meta-analysis	19
Lelliott & Roddnick	(2010)	Broad Astronomy Content	International	Peer-reviewed	Research Synthesis	103
Bretones & Neto	(2011)	All	International	IAU Proceedings	Descriptive Statistics	283
Fitzgerald et al.	(2018a)	Robotic Telescope Education	International	Peer-review, proceeding, theses & Dissertations	Descriptive Statistics	245
Pitout et al.	(2019)	Broad (1976 to 2019)	France	Peer-review, proceedings, theses, other	Descriptive Statistics	115
Mauricio & Bretones	(2019)	Broad (1999 - 2016)	Portugal	Master and Doctoral thesis	Descriptive Statistics	116
Tomita et al.	(2019)	Broad (2007 to 2019)	Japan	Peer-review	Descriptive Statistics	105

Table 2. Keywords used in the literature search

Asteroids	Gravitational Waves	Seasons
Astrobiology	Gravity	Solar
Astronomy	Henrietta Leavitt Swan	Solar Systems
Astrophysics	Hubble	Space
Aurora	Hubble Space Telescope	Space Exploration
Big Bang	Kepler	Spectra
Blueshift	Light year	Star Cluster
Celestial Motion	Lunar	Stars
Comets	Lunar Phases	Stellar
Constellations	Meteors	Sundial
Cosmic Microwave Background	Milky Way	Sundial
Cosmology	Moon	Supernova
Dark Energy	Moon Phases	Telescopes
Dark Matter	Orbits	Tides
Earth	Parsec	Universe
Eclipse	Planets	
Electromagnetic Spectrum	Quasars	
Exoplanets	Radio astronomy	
Fusion	Redshift	
Galaxy	Satellites	

There is a similar overlap between earth sciences education, geosciences education and AER. This is less to do with the nature of the content of each field in that, to some extent, they only overlap at approximately the Earth's surface and atmosphere with astronomy everything above and earth science everything below (roughly speaking). The overlap has more to do with the fact that earth sciences and astronomy (sometimes termed "space science") are merged together in many curricula around the world (Salimpour et al., 2024) and taught as a combined subject area. Although it is true that the current global challenge of the era – climate change – requires understanding of concepts in both areas to fully understand the scientific issues of this phenomena.

Less clear cut is the line between what is a 'research article' and what is essentially a presentation of practical or general information or even simple intention. It has been shown that the more informative about the particular approach and the more data-based the paper, the higher the impact, at least in terms of citations, in certain fields of AER (Fitzgerald et al., 2018a). While, to some extent, the answer to this question is more up to the database user and what they are looking for, if a particular item was either just an abstract or not much more than an extended abstract then it was not included.

Any article that was published in a reputable journal by a reputable publisher, any thesis that was granted by a reputable institution, any book published by a reputable publisher, any conference proceedings published from a reputable conference were included with no judgement on the depth or quality of the research within, beyond tagging whether the item was peer-reviewed or not peer-reviewed.

2.2 Broadening iSTAR categories

The iSTAR database (`https://www.istardb.org`), where we have uploaded all abstract data from this current study that was not already in the database, is the latest, and only currently actively maintained database for AER. Earlier attempts such as SABER

Table 3. An explanation of the key overarching categories in the current iteration of iSTAR.

Category	Explanation
Construct	Refers to the broad nature of the focus of that research such as content knowledge, spatial thinking or attitudes to provide three examples.
Content	Refers to the scientific content (if any) addressed in the research context.
Methodology	Refers to the research approach which could be Quantitative (driven only by numbers and statistical analysis), Qualitative (driven by descriptive analysis), and Mixed-methods (a combination of the first two approaches)
Publication Type	Refers to the type of output: Article, Book, Conference Item, Edited Book Chapter, Monograph, Other, Thesis
Resource Type	Refers to the nature of the output: Curriculum/Program Description or Report, Curriculum/Program Evaluation, Empirical Research, Historical, Literature Review, Position Paper/Editorial, Resource Guide/Bibliography, Theoretical Research
Target Group	Refers to the participants (if any) in the research: Adult Learners, College/University Faculty, Multi-aged groups, Other, Second Language or Heritage Language Learners, Students, Teachers

(2001-2010) (Bruning et al., 2006) and STEMdex (a successor to SABER at Caltech)(Bartolone et al., 2014) are no longer available. As this is the case, we compared the results of the search to the existing iSTAR database and added in newly found articles. There is no way to know what percentage of the true number of articles this database represents, but it can be said that at this stage it is highly representative of journal articles and conference proceedings with less certainty about book chapters and theses, both of which are harder to find and source. At the time of this writing the number of English language publications stands at 2085. The original categorisation scheme outlined in the 'first light' article for iSTAR (Slater et al., 2016) was based on the initial set of just over 300 dissertations. The extensive literature search that underpinned the research in the paper expanded the original categorisation scheme of the initial iteration of iSTAR, some of the key categories are explained in Table 3.

With the order of magnitude jump in the size of the database, this needed to be expanded to incorporate new additions to the classification scheme simply due to the larger number of construct categories that were able to be identified in the broader set of literature. The construct categories were also expanded to allow intercomparison with curriculum research (Salimpour et al., 2020) and the Big Ideas in Astronomy document (Retrê et al., 2019).

The redevelopment of the Content categories in the iSTAR database was a multistage process. The first stage involved mapping the initial iSTAR astronomy Content categories to the themes developed through the exploration of curricula by Salimpour et al. (2020), and concurrent mapping to the Big Ideas in Astronomy (Retrê et al., 2019). This is shown in Table 4. Next each author went through and recategorised the publications in iSTAR using the updated categories. Each publication was given a score based on how many authors agreed with the categorisation. A publication with a score of four meant that all authors listed the publication in the same Content category. The authors then met and went over the Content categories and discussed any re-categorisation for items that scored two or less.

The Construct categories was also refined owing to the increase in publications in the database. The original constructs were limited in their reach, and some were fine-grained. The first stage involved re-categorising the fine-grained constructs into overarching constructs. Next the authors went through a subset of randomly selected articles to pilot the new construct categories. This led to some new constructs appearing, and so the categorisation of the constructs involved an iterative process with an emergent coding approach. Next each author went through and recategorised the publications using the updated Construct categories. Each publication was given a score based on how many authors agreed with the categorisation. A publication with a score of four meant that all authors listed the publication in the same Construct category. The authors then met and went over the Construct categories and discussed any re-categorisation for items that scored two or less.

The resulting Content categories can then be intercompared between the Salimpour et al. (2020) review of curriculum around the world, the Retrê et al. (2019) definition of the Big Ideas and the Content categories (Table. 4). As the three approaches have three different origins and foci - the curriculum review focussed on what content is mandated in curriculum around the world, the Big Ideas document focussed on what content is necessary for astronomical literacy and the Content categories focus on what content is being researched - the match is not one-to-one.

For instance, the Big Ideas document focuses on the conceptual knowledge of the astronomical universe. It does not necessarily include some of the skills necessary to undertake astronomy nor the more fundamental physical or mathematical concepts necessary to build or apply this conceptual knowledge. Hence, some topics in the iSTAR Content categories do not have analogues in the Big Ideas - e.g. Gravity, Light, Particle Physics.

Gravity is used an overarching term that captures the concepts to do with weight particularly on different planets, orbits which encapsulates Kepler's Laws particularly, and gravitational waves which is a blurry line between Physics Education and Astronomy Education. The mapping of Physics to Particle Physics is because when reviewing curricula that is where Physics is particularly where this content manifests. Some topics in physics for example spectra and the nature of light are more appropriately captured under Optics, is predominantly present in general science curriculum at lower grades, with only more advanced notions being present in high school physics.

Similarly, a direct overlap between the iSTAR Content categories and the curriculum review is not necessarily present. The reasons here are more straightforward. Some astronomical content is not within the school curriculum worldwide - e.g., High Energy Astronomy, while some Content categories are too skills focussed (e.g., Instrumentation/Techniques, Mathematics/Numeracy) to appear within a school curriculum focused on conceptual knowledge.

3 Results

3.1 The landscape of Astronomy Education Research

3.1.1 Journal and Conference Proceedings distribution

The four astronomy education-focussed journals (Astronomy Education Review, RELEA, JAESE, and AEJ) mentioned previously make up nearly 30% of journal articles in the discipline. Aside from a recent special issue on AER in the Physical Review Physical Education Research (Bailey and Plummer, 2018), the rest of the articles are spread through 195 journals, not including

Table 4. Mapping iStar Content categories to Salimpour et al. (2020) curricular categories to the Big Ideas in Astronomy

Salimpour et al. 2020	Big Ideas	iSTAR Content categories
Astrobiology	Big Idea 10	Astrobiology
Celestial Motion	Big Ideas 2 & 3	Celestial Motion
Cosmology	Big Idea 6	Cosmology
Exoplanets	Big Idea 10	Planetary Sciences/Exoplanets
Extragalactic	Big Idea 9	Galaxies/Extragalactic
Galactic	Big Idea 9	Galaxies/Milky Way
Gravitational Waves		Gravity
History and Culture	Big Idea 1	Culture and History
Optics	Big Idea 4	Light
Planetary Science	Big Idea 7	Planetary Sciences / Not Exoplanets
Radio Astronomy		Radio Astronomy
Space Exploration		Space Science
Stars	Big Idea 8	Stars
Physics		Particle Physics
Measurement		
		High Energy Astronomy
		Mathematics / Numeracy
	Big Idea 4	Scale and Size
		Miscellaneous Astronomy Content
		Other
		No Astronomy Content
		Blank
	Big Idea 4	Computational Astronomy/Big Data
	Big Idea 4	Instrumentation / Techniques
	Big Idea 11	

edited conference proceedings. The top ten most prominent journals are summarised in Table 5.

3.1.2 *Temporal distribution*

In Figure 2, we present a histogram of the number of publications identified by year. We can see that there are four main eras in AER publications.

1. Era 1: Prior to 1970 publication in astronomy education research topics seemed to be quite rare with only one or two articles per year on the topic.
2. Era 2: From 1970 to early 1990s, the rate undertook a slight step-up change with an average of 5 or so articles per year. We hypothesise that the Space Race of the previous era and its education programs contributed to this.
3. Era 3: From the early ~1990s up until the ~2009s there was quite a distinct rise in AER publications. It was during this era that early researchers that specifically focussed on AER really started appearing and publishing. It is during this period that AER is being recognised as its own discipline, separate from PER (Eriksson, 2014).
4. Era 4: From the middle 2000s onwards to the current era, the publication rate has somewhat plateaued at a steady rate of roughly 50 articles per year with some prominent spikes due to major International Astronomical Union (IAU) meetings and other conferences focussed on AER.

Table 5. Top ten most prominent journals containing AER articles.

No	Journal Name	Percentage (%)
1	Astronomy Education Review	22.6
2	International Journal of Science Education	5.8
3	Research in Science Education	3.6
4	Journal of Geoscience Education	3.3
5	Journal of Astronomy & Earth Sciences Education	3.1
6	Science Education	3.0
7	The Science Teacher	3.0
8	Journal of Science Education and Technology	2.9
9	American Journal of Physics	2.8
9	Physical Review Special Topics - Physics Education Research	2.8
10	Publications of the Astronomical Society of Australia	2.3

Bailey (2011) found there were significant amounts of education abstracts from the American Astronomical Society (AAS) conferences over time. This broadly mirrors the increase in publications over this period (see Fig. 2), although abstracts alone are not enough to include in this survey or iSTAR itself as a 'published article', it is a further independent indicator of the rise of activity during the period - at least in the United States.

The distribution of types of articles is dominated by journals (~50%), conference proceedings (~30%), theses (~14%) and book chapters (~5%). When looking at conference proceedings we see five distinct peaks; In 2008, the proceedings from a special session of the International Astronomical Union (IAU) General Assembly (GA) in Prague (2006) were published in book form (Pasachoff et al., 2008), in 2011, there was the proceedings after an Astronomy Society of the Pacific conference (Jensen et al., 2011), in 2014 and 2015 conferences proceedings were published from the 2012 IAU GA meeting in China (IAU, 2015) and the 2013 Astronomical Society of the Pacific "Ensuring STEM Literacy" conference (Manning et al., 2014). In 2018 & 2019 there was the proceedings of the first AstroEdu conference in Garching, Germany (Eriksson et al., 2019) and the 2017 and 2018 Robotic Telescopes, Student Research and Education conferences (Fitzgerald et al., 2018b, 2019a). The latest conference series in the time period were the proceedings after the 2018 IAU GA in Vienna (IAU, 2020) and the IAU Symposium S367 "Education and Heritage in the Era of Big Data in Astronomy (Ros et al., 2022).

From 2017 we see a general decline in the numbers of AER publications. We also see a steep decline between 2019 to 2022, which we partly ascribe to the effects of the COVID pandemic, which meant that researchers were not able to do educational research with teachers and students. However, it is also true that more recent years may undercount the number of articles because, even though the "main" journals and conference series have been searched and included, more recent publications in more obscure locations can take longer to be identified and placed in the archive. Theses are typically challenging to identify given that they are often within institutional repositories or physical archives. Further, while some journals are stated as being published in one year, they are sometimes not available online until a year or two after. Some articles exist in an online-first format waiting to be placed in a specific journal issue or once published are backdated a year or two to the completion of the editing process rather than the publication date. A combination of these factors is the likely explanation for lower levels of publications in recent years.

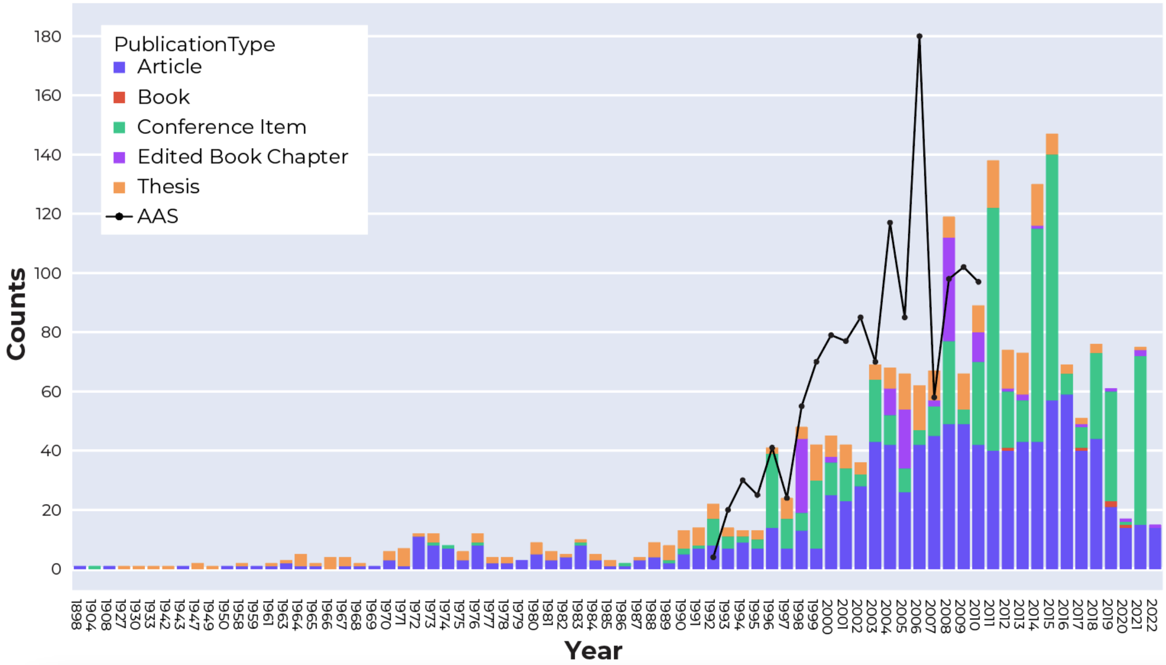

Figure 2. This plot graphically represents the overall development of AER publications over the years 1898-2022. The line overlaid presents Bailey (2011)'s plot of number of AAS education abstracts.

3.1.3 Geographic distribution

In terms of geography, the dominant country of origin, as denoted by author affiliation, for this research is by far the USA with ~62% of publications, and ~2% as part of collaborations with other countries. This is likely a combination of a few different factors, all of which largely stem from a unique situation where universities all over the USA have general science education requirements. Various forms of ASTRO101 (introductory astronomy) courses are one of the most popular. This is not true for most of the rest of the world. This has allowed university faculty large numbers of quite accessible astronomy students upon whom to research as well as teach. This is a clear feature of research stemming from the third era of rapid growth (1990-2009).

Other contextual factors as to why the USA produces the most research historically include large funding sources from NASA EPO (which dried up somewhat in 2013 due to funding cuts), the National Science Foundation (NSF) and other large government agencies as well as a relatively permissive (on average), although still robust, Independent Review Board (IRB)/Ethics system compared to other rich western democracies. A full list of countries of origin above 1% of the total publications is presented in Table 6. It should be noted that ~4% of the total publications involve multi-nation studies.

It can be seen in Figure 3 that for the majority of the recent era, AER has been most commonly undertaken in the USA. However, in recent years, this has been shifting from 2015-2018 where it was roughly equal USA/non-USA output, to 2019-2022, when there is a clear change to the majority of research being undertaken outside the USA. This is a feature specifically of the USA. Over the period of 2005 to 2019 (the most recent non-COVID affected era), non-USA publication rates remained remarkably constant, while the USA showed a fairly constant decrease from 2013 after a relatively stable period between 2005-2012. This is shown in proportion in Figure 3 and later in Figure 4. The change in proportion is due to the decrease in rates of research publication in the USA whilst the non-USA research publication rate remained relatively steady.

Table 6. Countries of origin of AER with over 1% English-language publications.

Countries	Count	Percentage
United States of America	1178	56.5
Australia	91	4.36
United Kingdom	82	3.93
Canada	74	3.55
Turkey	51	2.45
Japan	44	2.11
France	30	1.44
Spain	28	1.34
South Africa	27	1.29
Germany	25	1.2
Greece	24	1.15
Israel	23	1.1
Brazil	22	1.06

There is no certain data and no certain way to understand why this is the case. However, it is the case that in 2013 there was a significant reduction in NASA EP/O funding which led to less positions in astronomy education and AER which should have had a downstream effect on publication outcomes. In the same year, the AAS decided to terminate the journal "Astronomy Education Review" (Fraknoi, 2013) which led to one less high quality place to publish - in fact, the journal representing one quarter of all AER output. The magnitudes of both of these effects are large, but were mostly geographically limited to the USA.

3.1.4 On publication types

Overall, articles have been the dominant format overall (1.94%) in total and across all the four eras (Figure. 4). While they are still the dominant form of publication, over time the conference proceeding has quickly grown as a publication option with (0.22%) in Era 3 and (0.43%) in Era 4 being conference proceedings. This may simply be that there are more conferences and more capacity for easy communication nowadays than in earlier eras. Book chapters only make up a small fraction of the total and the

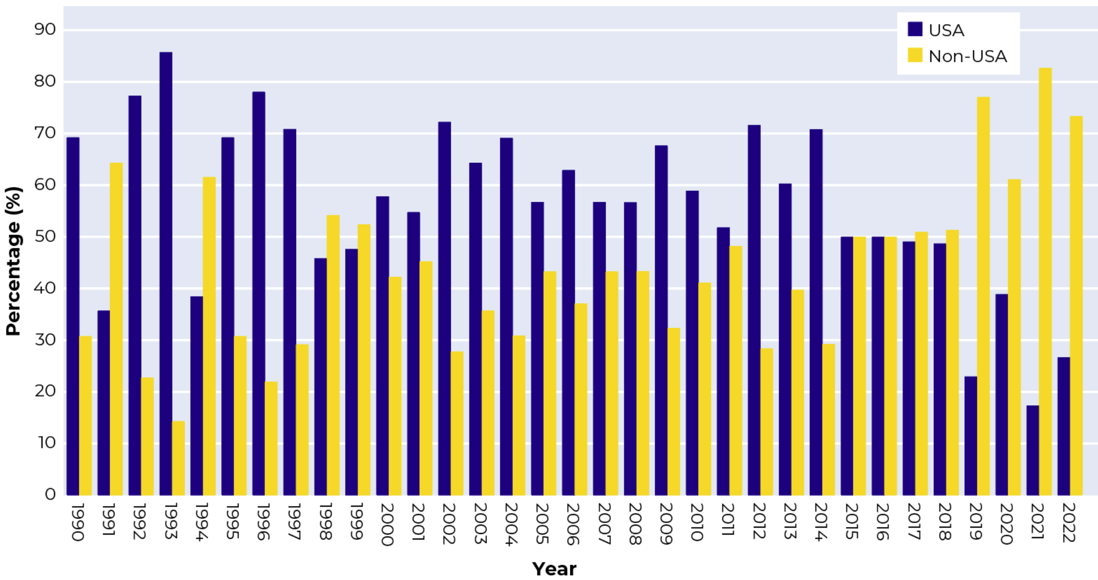

Figure 3. This diagram represents the distribution between USA and non-USA publications from 1990 to 2016. Note the clear shift from 2016 in favour for non-USA publications.

Figure 4. Visualisation showing the distribution of publication types across four eras. Era 1 prior to 1970, Era 2 between 1970 and 1990, Era 3 between 1990 and 2009, and Era 4 beyond 2009. Notice that articles are the dominant publication type across all four eras. Note: Thesis encompasses both Masters and PhD

proportion of theses has decreased over time.

3.1.5 On resource types

When analysing the database for resource types identified and defined by the authors, we again sometimes needed to assign code to a source belonging to more than one category, hence the sum of resource types will add up to be more than 100%, as seen in Figure 5. In terms of resource types, we see that three different types dominate: Curriculum/program description or reports is a majority (~43%), Empirical research (~37%), and Position papers/Editorial (~18%). Of these, only the empirical research is thoroughly peer-reviewed before publishing. These are followed by Curriculum/Program Evaluation papers (~12%) and Resource guides/Bibliography (7%). We find very little theoretical research, literature reviews and resources dealing with historical aspects of astronomy education and research (about 7%, in total).

3.1.6 ASTRO 101 and AER

It is relevant looking a bit deeper into the ASTRO 101 course in the USA as it forms a large percentage of AER research and, hence, its history and development. This is an astronomy course that is taken by non-science major students, as an introduction to science. There are other courses as well, but ASTRO 101 is one of the most popular, with many thousands of students every year across the country. The course has been the setting for much AER publication for quite some time and has a long history, even though it is in the early 2000s that the course, and its number of participants, increased significantly. After asking the astronomy community in the USA for historical evidence of the course, it appears that the inception of ASTRO 101, or similar introductory astronomy courses in the USA, can be traced back to various periods, with no single definitive starting point. A summarised timeline may look as below (based on anecdotal evidence):

- Early Instances in the 20th Century: ASTRO 101-type courses began to emerge more prominently in American universi-

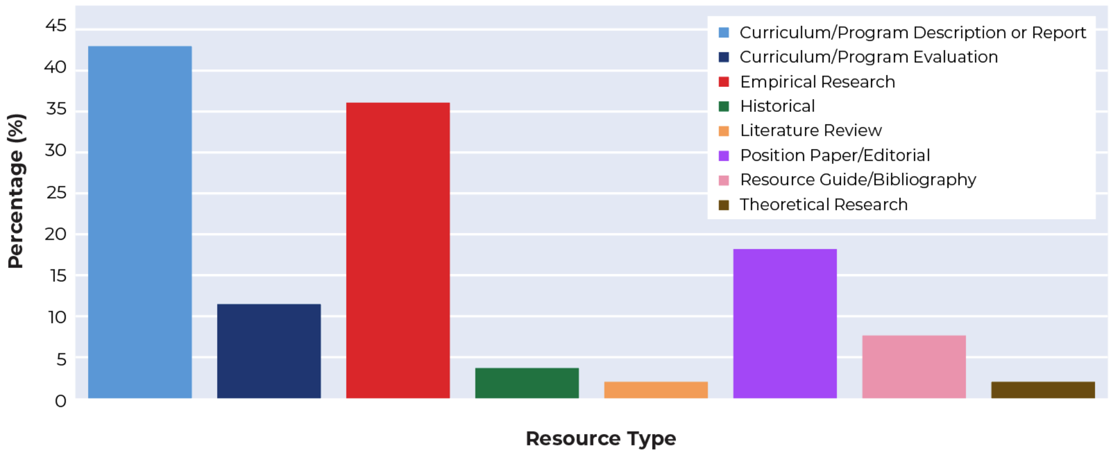

Figure 5. Distribution of the different resource types. It should be noted that some studies contain two or more of the Resource Type.

ties around the mid-20th century. For instance, Penn State University likely started offering a version of Astro 101 in the early 1950s, and the University of Illinois had a similar course by the mid-1930s.

- Richard Emmons' Innovations (1945-1950): A notable early example of such a course was taught by Richard Emmons at Kent State University, Canton, Ohio, around 1945-1950. This course was considered innovative for its time, suggesting that the concept of a general astronomy education course was not widespread before the 1940s.
- High Schools and Colleges in the 19th Century: While not exactly ASTRO 101, astronomy was a part of high school and college education in the mid to late 1800s. However, the teaching of astronomy suffered a setback in 1892 when it was eliminated as a college entrance requirement by the "Committee of Ten".
- Textbooks Indicating Earlier Origins: The existence of astronomy textbooks dating back to the 19th century (like Henry Kiddle's "A Short Course in Astronomy" from 1870) suggests that introductory courses might have been in place during that time, although these were likely more technical and aimed at science majors.
- Late 19th Century Courses: By the late 19th century, some colleges like the University of Kansas (since 1876) and Albion College (since at least 1884) were offering astronomy courses, but these might not have been introductory courses in the modern sense.
- Vassar College's 1865-66 Catalogue: The inclusion of a general course on astronomy in Vassar's 1865-66 course catalogue indicates that astronomy as a subject was being taught, but it's unclear if this was a general education course akin to ASTRO 101.
- Historical Origins: The roots of astronomy education go back even further. In classical education, astronomy was a core subject from as early as the 6th century BC, although these were not structured like modern ASTRO 101 courses.

Given this information, the concept of ASTRO 101 as an introductory, general astronomy education course for non-majors likely started taking shape in American universities around the 1940s to 1950s, with roots and precursors dating back to the 19th century. It is likely in this context that the rise in AER in 1960s and 1970s started taking place. More research on the historical development would be interesting to explore, but it is beyond the scope of this paper.

To explore the impact of ASTRO 101 on AER, we re-coded the papers based on their abstracts into "early undergraduate research" and "school research" and "neither". We use "early undergraduate" rather than ASTRO 101 as the terminology is largely a North American term not used elsewhere. The "school research" category refers to research done in the context of formal school education prior to attending University. The "neither" category can include research at both levels or research at neither (e.g. postgraduate, general public, amateur astronomers, informal environments, theoretical, historical, literature reviews, exploring topics without specifying an age level of the student).

This was a straightforward process with only one particular aspect where the categories overlapped significantly - in the training of pre-service teachers. We chose to classify pre-service teacher research as "school" research as the focus is on the training of school teachers rather than ASTRO 101, even though it is at roughly the same academic level and generally similar population, they do tend to be taught as different subjects in different departments. In a similar vein, we classified research into astronomy instructors who teach ASTRO 101 as undergraduate research. So, if anything, the amount of undergraduate-focussed research is slightly underestimated in this coding scheme. This was done in an endeavour to broadly show the distribution of undergraduate research vs school research in the USA versus the rest of the world to illustrate the huge positive impact that the availability of ASTRO 101 courses has had on AER but also its relatively limited scope to the United States. The relative rates of school research to ASTRO 101 research for the USA and the rest of the world is shown in Figures 6a and 6b.

3.2 Target Groups of research

The target groups of research were easily categorised, and these are summarised in Figure 7. It can be seen that the majority of target groups are students, with a fairly even distribution across middle school, high school and college with somewhat less students in elementary school and not a lot of research with pre-primary students. The "Other" category contains research where the target group is not clear or is not a traditional teacher/student/adult learner group. Two other target groups exist, "Parents" (<1%) and "Second language students" (0). These are not displayed on this figure due to the small numbers assigned to these groups.

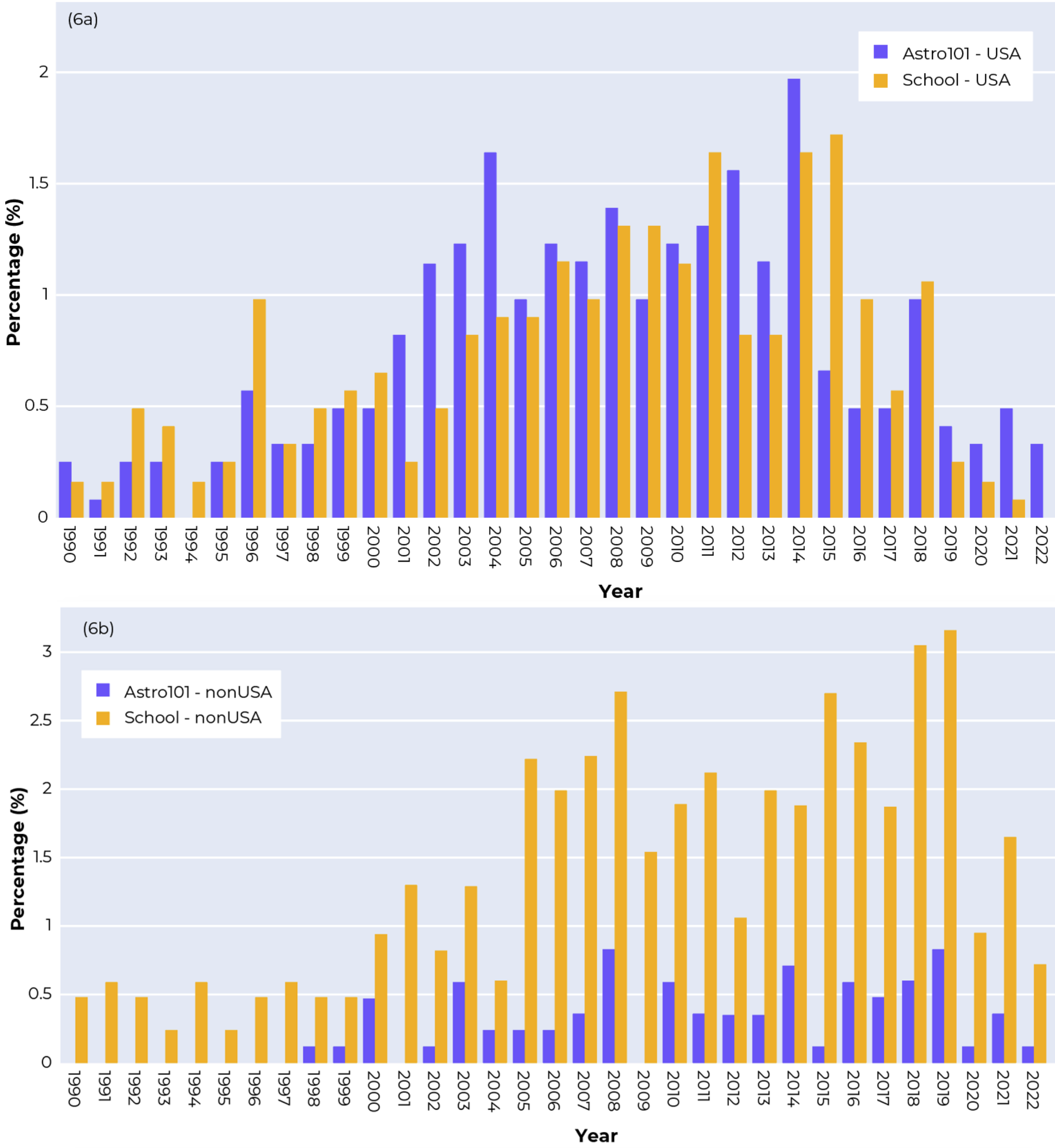

Figure 6. Visualisation comparing (a) the USA, and (b) the rest of the world in the context of ASTRO101 and school research.

3.3 Constructs

As shown in Figure 8, there are a variety of constructs addressed by the research. A description of each construct is provided in Table 7. Again, a publication can be tagged with more than one construct, leading to the total sum being bigger than 100%.

The majority (~48%) of the constructs identified fell under "General Teaching" which is less focussed than most other constructs considered. Since nearly half of all the studies were General Teaching, we have chosen to remove this from Figure 8 to make more apparent the distribution of other, more focussed, constructs. The next top two constructs were Content Knowledge, which focussed on "understanding" and Affective which focusses deeper "mechanisms" that influence understanding. The next construct is "belief/identity", which is sub-construct of Affective and encompasses notions such as student attitudes, self-efficacy and identity. The majority of the other remaining constructs are more related to "understanding" than to "affect".

Taking a slice of the data over the four eras (Fig. 9), "Content Knowledge" has been the most common Construct across all eras. Engagement has trended upwards over time in particular, but most non-content knowledge constructs have made gains in proportion across the four eras. The first two eras were largely dominated by the "Content Knowledge" construct but over time this has led to more diverse distribution of constructs being published in Era 4.

3.4 Content landscape

By taking a slice across the Content category and mapping the Content categories to the 16 categories developed from the curricular analysis by Salimpour et al. (2020), a snapshot of the distribution according to content was extracted, which is shown in Table 8. Of the 2085 English language publications currently in the iSTAR database, 1047 had a content focus that was classifiable. We have chosen not to include "Miscellaneous Astronomy

Table 7. A description of the constructs tagged iSTAR

Construct	Explanation
Academic Social/Discourse	This captures publications where the focus is more geared towards academic discussions that include but not limited to theoretical, conceptual or methodological framing.
Citizen Science	Publications that focus on various aspects of citizen science. Where citizen science is defined as endeavours where the public (multi-aged groups) contributes to authentic scientific projects.
Affective	This construct captures those publications that explore in essence some deeper mechanisms that influences various interactions with astronomy as a discipline. The fine-grained sub-constructs are "Belief/Identity" and "Motivation/Attitude"
Belief/Identity	This sub-construct encompasses affective aspects related to belief and identity.
Motivation/Attitude	This sub-construct encompasses affective aspects related to motivation and attitude.
Conceptions/Conceptual Change	This encapsulates publications that focus on not only identifying "mis-"conceptions, but also various approaches that bring about changes in understanding of concepts in astronomy.
Content Knowledge	This construct captures publications which focus on the content of astronomy
Disciplinary literacy	The construct is captures publications where the focus is on the investigation of disciplinary literacy either in astronomy or using astronomy as a context for exploring disciplinary literacy in both STEM and non-STEM subjects
Engagement	This overarching construct encompasses the act of engaging with various groups. It is different the construct of engagement from an affective or cognitive lens.
Astronomy and Society	This sub-construct covers engagement and interaction of astronomy with society
Public outreach	This sub-construct covers engagement with public covering both excursions and incursions
Public viewing	This sub-construct covers engagement with the public in the context of telescope of unaided eye viewing during the day/night.
General Teaching	This is an overarching construct covering teaching broadly. It captures publications that investigate how astronomy is taught.
Assessment	This sub-construct encompasses publications that focus on assessing some aspect of astronomy. This could be the development of concept inventories, ways to assess skills and various theoretical and pedagogical aspects of assessment
Curriculum	This sub-construct encompasses publications where the focus is on the development of some sort of curriculum. This can be curriculum at a national level or at the classroom level, for example, a teaching sequence.
Inquiry-based Learning	This sub-construct encompasses publications that are centred on the pedagogical approaches inspired by or draw on inquiry-based learning.
Teaching Resource	This sub-construct encompasses publications where the focus is on the development of resources for teaching astronomy and its cognate fields.
Multidisciplinary	This construct captures publications where the focus is multidisciplinary teaching and learning using astronomy as context or driver.
Nature of Science	This construct captures publications which explore the overarching idea of Nature of Science in the context of astronomy.
No Specified Construct	Publications that did not have any specified construct
Policy analysis/curricula	This construct captures publications where the focus is on investigating policy documents, for example, curricula, related to astronomy education.
Project and Resource Evaluation	This construct captures publications where the focus is on evaluating projects or resources developed for astronomy education, outreach or development.
Reasoning	This overarching construct captures the underlying reasoning processes that underpin teaching and learning, and also how those processes are used in understanding various topics in astronomy. The sub-constructs are derived from research that explores each of these sub-constructs
Qualitative Reasoning	This sub-construct captures publications where the focus is on exploring qualitative reasoning in various contexts. This be in teaching and learning of astronomy or using astronomy as way of investigating and developing this form of reasoning.
Quantitative Reasoning	This sub-construct captures publications where the focus is on exploring quantitative reasoning in various contexts. This be in teaching and learning of astronomy or using astronomy as way of investigating and developing this form of reasoning.
Spatial Reasoning	This sub-construct captures publications where the focus is on exploring spatial reasoning in various contexts. This be in teaching and learning of astronomy or using astronomy as way of investigating and developing this form of reasoning.
Visual Reasoning	This sub-construct captures publications where the focus is on exploring visual reasoning in various contexts. This be in teaching and learning of astronomy or using astronomy as way of investigating and developing this form of reasoning.
Representations / Visualisations	This construct captures publications which explore the overarching area of representations and visualisations in astronomy or teaching and learning of astronomy. This construct takes a broad view of representations to encompass, language, signs, symbols, diagrams, data visualisations, infographics and much more.
Research and Methods	The focus of this construct is publications where the aim is to explore the theoretical and methodological approaches to conducting astronomy education research.
Scientific Inquiry	This construct captures publications which explore the overarching ideas and skills related to Scientific Inquiry in the context of astronomy.
Skills	This overarching construct captures publications which explore the various skills that are broadly addressed astronomy education in both formal and informal settings.
Authentic Research	This sub-construct captures publications which investigate the use of authentic research experiences in astronomy education. This could be the use of data or instruments in the teaching and learning of astronomy.
Computational	This sub-construct captures publications where the focus is on computational skills and knowledge in the teaching and learning of astronomy.
Telescope Use	This sub-construct captures publications where the focus is on the use of telescopes in the teaching and learning of astronomy.
Teacher education	This construct captures publications which explore astronomy education within the area of teacher education. This includes both pre- and in-service teachers.

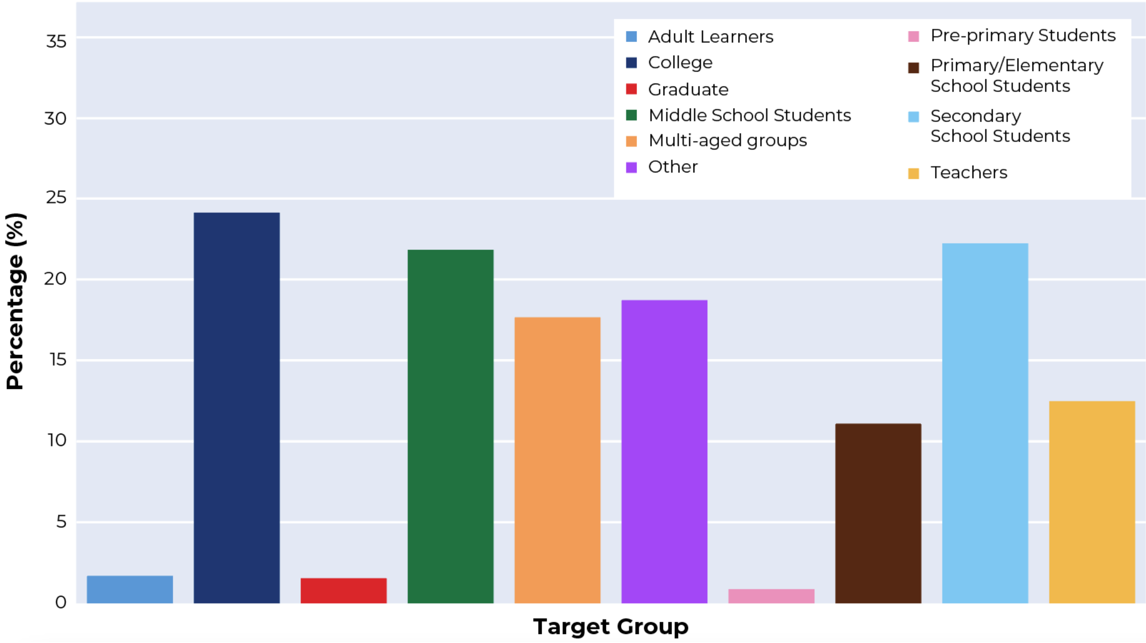

Figure 7. The diagram represents the distribution of target groups in AER in the iSTAR database.

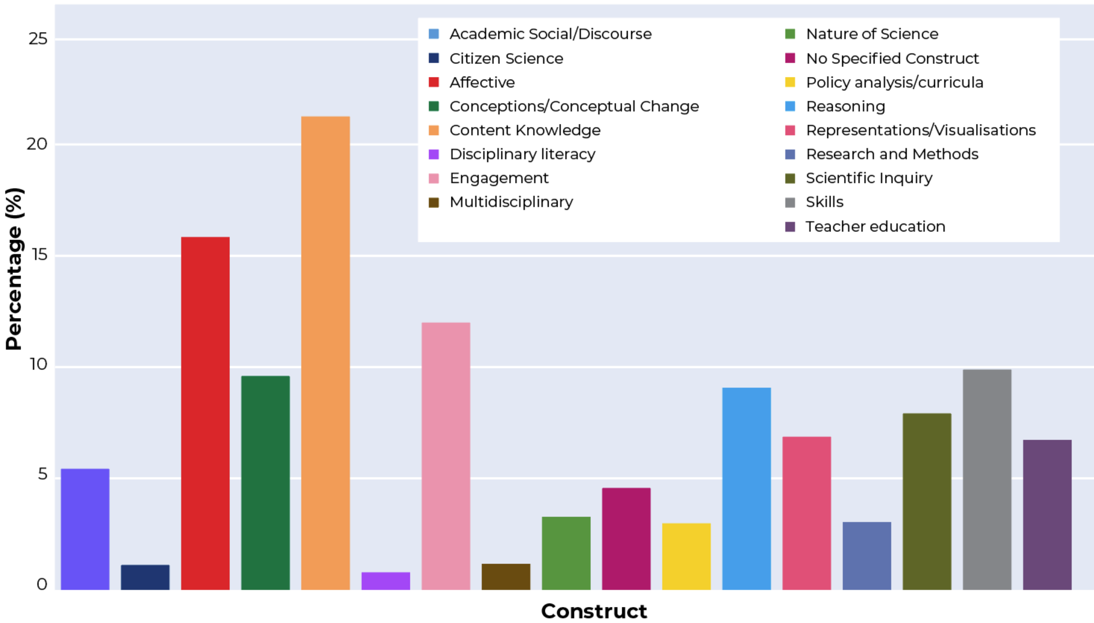

Figure 8. The diagram presents the distribution of Constructs. Note that one publication can be tagged with more than one Construct. Note that the Construct "General teaching", which represents 48% of the Constructs is not presented on this chart to allow differences between the other Constructs to be apparent.

Content (N: 600, ~28%) and "No Astronomy Content" (N: 393, ~18%) as these topics are both very large and do not provide insights to the general distribution of astronomy content. From Table 8, we clearly see that a few contents stand out. First, with above 15%, we have: Instrumentation/Techniques (15.8%) and Celestial motion (15.5%). Then, between ~5%-10%, we have Planetary sciences (not Exoplanets) – typically Solar System content - (6.6%), Stars (5.1%), and Culture and history (4.7%). These are thus the most common contents covered by AER historically, closely followed by Size and scale, Cosmology and Light, all with around 3%.

Over the four eras Celestial Motion remains the most dominant of all time (0.66%) and across all eras (Fig. 10). Era 1 particularly focussed nearly exclusively on Celestial Motion and the Earth. Most other areas made mild gains in comparison to Celestial Motion. Instrumentation/Techniques standards out as a growth area likely to the fast increase in accessibility of astronomical instrumentation for education, particularly Robotic Telescopes (Gomez & Fitzgerald, 2017). Over time, this has led to relatively more diverse distribution of content areas being published in Era 4, especially in comparison to Era 1.

In the following, we explore the slices through the data looking at the relationship between the Content category, and the Construct and Target Group categories, revealing some interesting insights, presented in Figure 11. For example, Celestial Motion is a popular content and often addressed in connection to the constructs Content knowledge, Reasoning, Conception/Conceptual change, Representations, and Affective processes. This is not surprising since a large proportion of publications in AER over the years have investigated aspects of under-

Table 8. Number and proportion of publications when grouped by iSTAR Content categories. The top five have been highlighted.

iSTAR Content Categories	Number of publications	Percentage of publications
Astrobiology	22	1.1
Celestial Motion (e.g., seasons, lunar phases, eclipses)	323	15.5
Computational Astronomy/Big Data	25	1.2
Cosmology	64	3.1
Culture and History	97	4.7
Exoplanets (Planetary Sciences)	20	0.9
Galaxies/Extragalactic	4	0.2
Galaxies/Milky Way	8	0.4
Gravity (e.g., Orbits, Gravitational Waves, Weight)	52	2.5
High Energy Astronomy	6	0.3
Instrumentation/Techniques (e.g., Robotic Telescopes, Spectroscopy, Photometry, Image processing)	329	15.8
Light (e.g., Optics, Fundamentals of Light, EM Radiation)	60	2.9
Mathematics/Numeracy	11	0.5
Particle Physics	2	0.1
Planetary Sciences (Not Exoplanets)(e.g., Asteroids, Earth, Mars, Solar System)	138	6.6
Radio Astronomy	29	1.4
Scale and Size	64	3.1
Space Science (e.g., Space Exploration, Spaceflight, Rockets)	18	0.9
Stars (e.g., Double Stars, Stellar Evolution, Sun, Variable Stars)	106	5.1

standing lunar phases. A very popular content area and well investigated using the mentioned theoretical constructs. A closely related content is the Earth, which contains understandings of day and night cycles and seasons. This is correlated with the same constructs as Celestial motion.

Instrumentation/techniques is a content area that has become more popular over the years with robotic telescopes, image processing and big data. This correlates well with Skills and Scientific inquiry, but also with Engagement. Next, we see that No astronomy content, which stands for almost 50% of all publications, correlates well with Engagement, but also with Academy Social/Disclosure and Affective. This is not surprising as topics around these topics do not necessarily have to specify a content area.

Finally, we need to mention Stars, which correlates with Skills and Scientific inquiry, and Planetary Science, which correlates with Content knowledge, Conceptions/Conceptual change and others. All these are maybe not surprising but what we also see is that some contents are not well represented in the database. For example, Space science, Relativity, Radio astronomy, Particle physics, Mathematics, High energy astronomy, Galaxies, and computational Astronomy/Big Data are under researched and do not correlate much with any constructs.

3.5 Content vs Target Groups

As can be seen in Figure 12, middle and high school students have been the most focussed on in general with Stars, Planetary Sciences, Instrumentation/Techniques, Earth and Celestial Motion being the most prominent. This pattern is largely replicated at the College level although with slightly more focus on Stars, Light and Cosmology. Primary/Elementary School focuses primarily on Scale and Size, Planetary Sciences, Instrumentation/Techniques, Earth and Celestial Motion with less focus on the more complex topics dealt with at higher grade levels.

One might wonder, considering that we have stated before that ASTRO101 was a large portion of AER research, why it is the

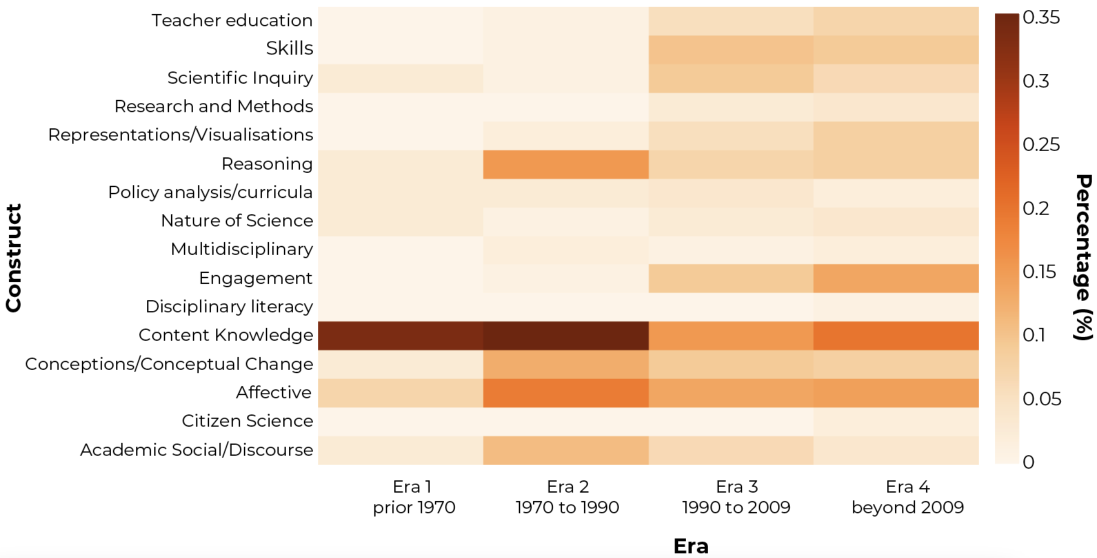

Figure 9. Visualisation showing the distribution of the various Construct categories across the four eras. Notice that over the years there has a been a steady focus on Content Knowledge aspects of astronomy education.

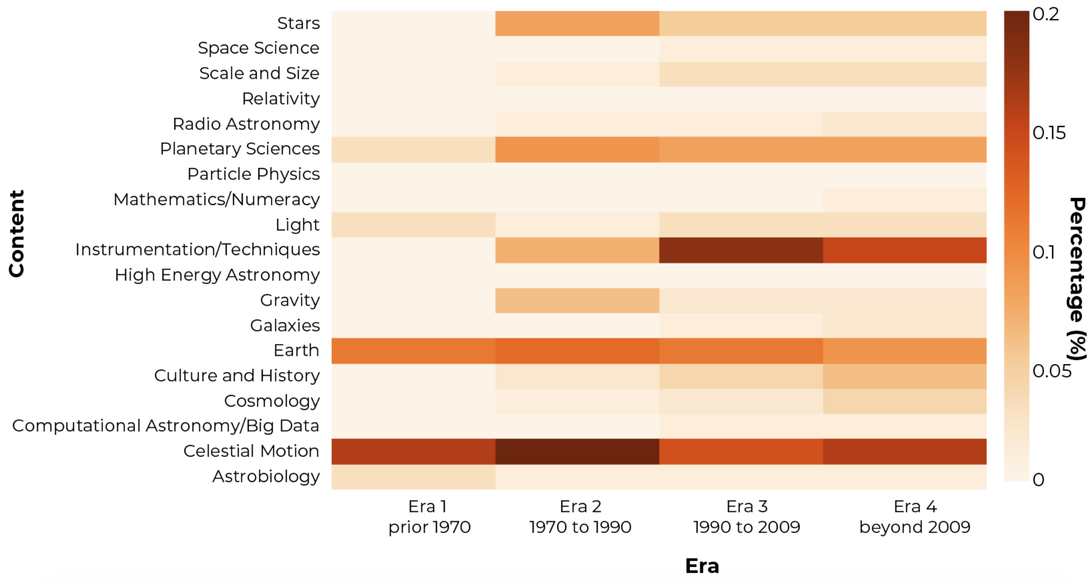

Figure 10. Visualisation showing the distribution of the various Content categories across the four eras. Across all four eras there have some dominant topics that have been explored in AER – Celestial Motion, Earth, Planetary Sciences.

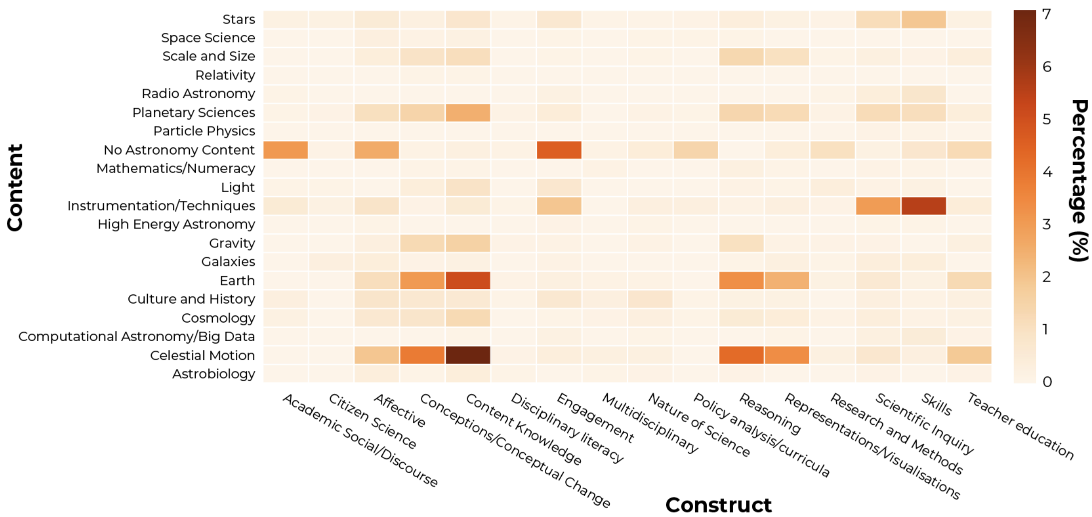

Figure 11. Heat map representing the relationship between Content and Constructs categories. The darker the colour, the larger the frequency.

school level that is more prominent. This is because ASTRO101 largely only occurs in the USA. Whereas school level research occurs both in the USA and forms most of the research outside of the USA.

Even within schooling itself, the distinctions between primary, middle and high school that is relatively common across the United States is not common amongst the rest of the world. The dominant format across the world is two separate schools usually just primary (K-6) and secondary (7-12) either separate or sometimes a whole school (K-12). Even though that may be the dominant format, it is likely not above 50% with significant variation in K-12 formats across the world. The main difference tends to be whether there is a middle school or not and whether “middle school” (5-8) is actually “junior high school” (7-9), although some have four (e.g. Portugal) or five (e.g., India) distinct divisions of K-12. While we have retained the initial primary, middle, high school coding in this research, in the future a more universal coding scheme is needed for this as classifying such research into these categories is problematic.

Figure 13presents the Content categories for two broad groups of teachers - those who are currently teaching (In-service) and those who are in preparation for teaching (pre-service). The dominant Content category is “Miscellaneous Astronomy Content” for both groups. There is a slight tendency towards more basic topics (Celestial Motion and Earth) for the pre-service teachers and higher-level topics for the in-service teachers.

3.6 Quantitative, Qualitative, Mixed Methods

Education Research – as well as other types of social science - has, traditionally, been split up into three distinct styles:

1. Quantitative, which is largely focusses on numerical explorations of social phenomena, these encompass research studies which use statistical methods (e.g., Freed et al., 2023; Schlingman et al., 2012; Slater et al., 2015a).
2. Qualitative which relies more heavily on rich descriptive data, where the data being analysed includes interviews, observational notes, video recordings, document analysis. The aim is to extract meaning and connections from the

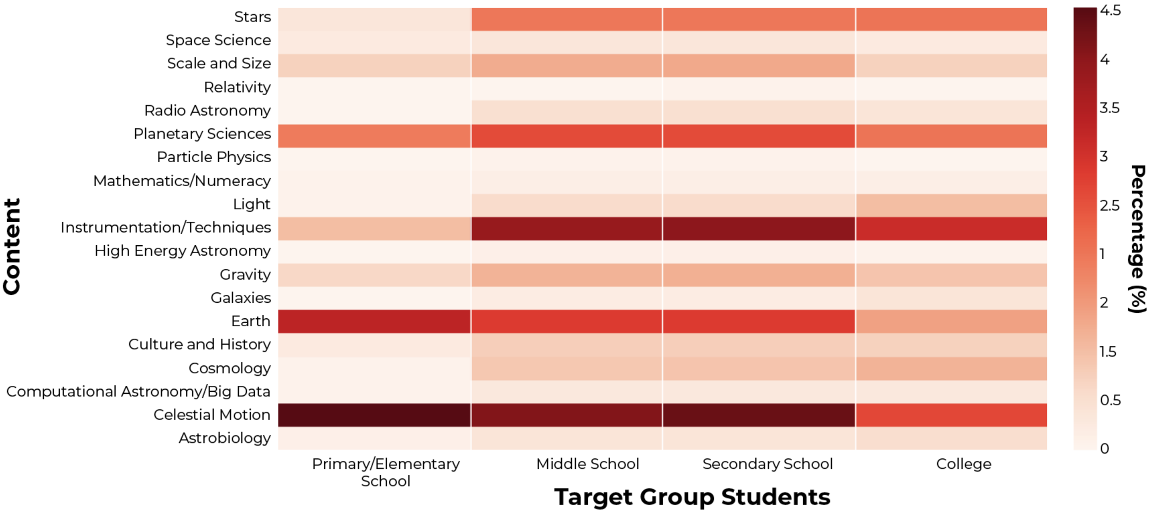

Figure 12. This figure presents a snapshot of what Content has been studied at which levels of school when students have been the focus of the research.

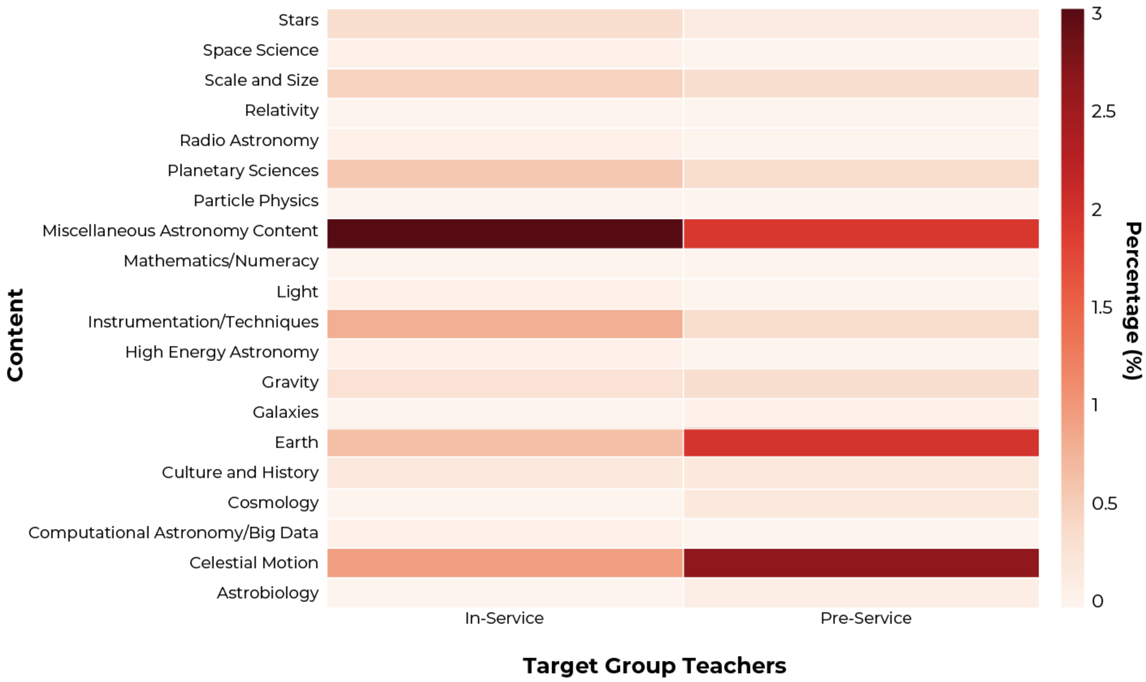

Figure 13. Content areas researched by target group of teachers.

non-numerical data (e.g., Cox et al., 2016; Eriksson et al., 2014; Hansen et al., 2004; Plummer, 2009; Skala et al., 2000); and

3. Mixed Methods, which is usually a blend of the two, it is grounded in the perspective that using a combination "numbers and words" provides a richer picture of the research aim (e.g., Fitzgerald et al., 2019b; Lamar et al., 2018; Salimpour, 2021; Tashakkori and Teddlie, 2010).

As can be seen in Figure 14, Mixed Methods is the most common method used overall. This is largely due to its dominance during Era 3 and Era 4. In Era 1 and Era 2, the field was dominated by Quantitative methods. The rate of purely qualitative studies over time is generally stable and the least common of the three.

4 Discussion

4.1 How has the landscape of AER changed over time?

In general, the paper has shown the overall features of the AER landscape over approximately the last century, although realistically the last 50 years, since the first sustained publications in AER appeared. The paper has shown that there are four distinct eras, in terms of publication numbers, during AER's rise up to the current plateau with a slight downturn apparent during the COVID era.

Despite the relative ease and commonality of conference proceedings (~30% of all publications), journal articles are the most common method of research publication over all time (~50%) followed by theses (~14%) and book chapters (~5%). Over the four eras considered, conference proceedings have become

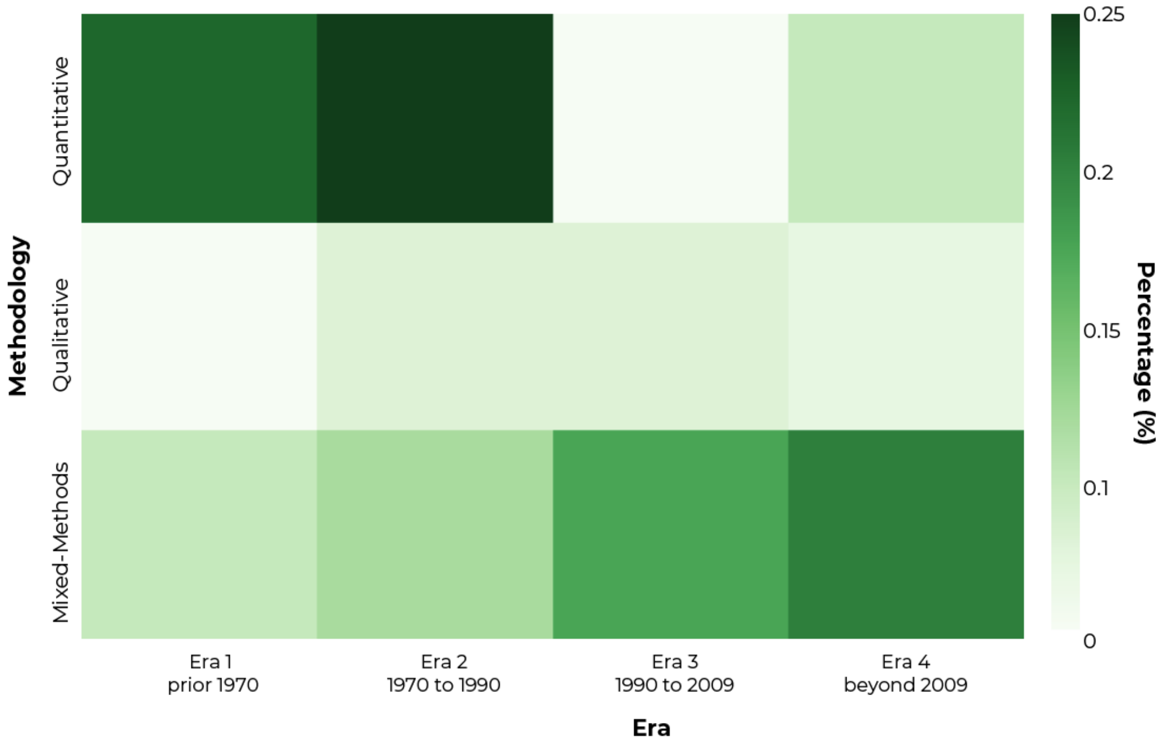

Figure 14. Visualisation showing the distribution of the four overarching research methods – Quantitative, Qualitative and Mixed Methods – over the four eras. There seems to be a move towards Mixed Methods research in AER.

much more prominent, and thesis have become less prominent with journal articles sustaining a relatively constant rate over time. This is likely due to the changing nature of research in general rather than anything specific to AER.

We find that while the USA has been the most prominent actor in AER for most of its history, within the last five or so years, there has been a distinct shift, most prominent in 2019, where this has quickly shifted to most AER being undertaken outside the USA.

Comparing the four eras, we see that there are shifts in the methodologies content and constructs considered in research. We discuss the methodologies in section 5.5 below. While Content Knowledge has always been the most prominent construct of research, in recent eras, the breadth of constructs has widened significantly. In Era 4, Engagement and Affective are nearly as common as Content Knowledge with representation from most other constructs apparent. This is a strong contrast to Era 1 and Era 2 where Content Knowledge was heavily dominant, to the extent that in Era 1 it appears that the vast majority was Content Knowledge.

In terms of the content considered, we see a similar development where in Era 1, the dominant content considered was Celestial Motion and Earth. These made up the vast majority of content considered but over the Eras, whilst these two still maintained their dominance, the diversity of content considered increased. In particular, Instrumentation/Techniques, Planetary Sciences, Culture & History and Stars are now fairly common with Cosmology and Scale & Size appearing more frequently.

4.2 What topics in AER have had significant numbers of publications? What topics have relatively small numbers of publications?

There is likely an understandable spread between target groups in AER - mostly students (~48%) with some teachers (~13%). There is no apparent reason to think that a particular broad group is being neglected or preferenced. The majority of content topics that have been studied is “Miscellaneous Astronomy Content” (~28% or 600 articles) which likely represents articles that are focussed on broad astronomy survey courses and those articles, where content was not the core focus of the paper.

Of the specific content topics, the results are not too surprising to someone working in the field with “Celestial Motion”, “Culture and History”, “Planetary Sciences/Not Exoplanets”, “Stars”, “Instrumentation/Techniques” being the most common with “Cosmology”, “Light”, “Scale and Size” also being relatively common. These are common topics across the spectrum of schooling and university. “Cosmology” has become much more common of recent note in the curriculum and in research (Salimpour, 2021) and the rise of educational robotic telescopes has led to much work on this “Instrumentation/Techniques” (Fitzgerald et al., 2018b)

What is missing from the spread of content topics is the “missing middle”, identified in curricula in Salimpour, Fitzgerald & Hollow (2024) where content seems to drop off at edge of the solar system (Planetary Sciences) ,with the exception here of stars which is a larger topic in the ASTRO101, and returns up towards the edge of the universe with Cosmology. The two Content categories “Galaxies/Extragalactic” (3 papers) and “Galaxies/Milky Way” (8 papers) have very few research publications, by actual volume and mass, making up most of the topics in the universe. For school-level curricula, this is likely because these topics simply don’t exist there - even though perhaps they should - (Retrê et al., 2019; Salimpour et al., 2024) and, hence, there is no opportunity for researching something that isn't taught. Why these topics are relatively less researched in ASTRO101 is not known as galaxies and the Milky Way is usually a topic in those versions of these curricula that attempt to survey all of astronomy.

The other three particularly neglected content topics are "Particle Physics", "High Energy Astronomy" and "Gravity". These are likely not so much neglected as not fitting well into the definition of an 'astronomy content area'. These three likely fall more directly into PER than AER.

4.3 To what extent does the research align with what is generally present in curricula and for scientific literacy?

There are two aspects to this question really in terms of curricula. There is the astronomy content of school curriculum across the world which is largely homogenous (Salimpour et al., 2020, 2024 (in review)) and the USA-focused ASTRO101 which can be quite heterogeneous but tending to attempt to cover most of the basics of astronomy to more or less depth, driven by university course requirements and the whims of the lead instructor, within whatever timescale is available. To some extent, this implies that the findings here about curriculum statements more directly applies to school-level AER and the findings here about what Big Ideas are covered by AER more directly applies to ASTRO101 survey courses, given the limited time allocated to astronomy in normal schooling preventing large survey courses. Analysis of curricula from 37 countries (Salimpour et al., 2020), and a more recent expanded ongoing analysis of 80 countries (Salimpour et al., in review) has shown that topics concerning Celestial Motion (e.g., seasons, lunar phases, eclipses) are overall most prevalent. This is perhaps in line with the research being done. Primary/Elementary and Middle school curricula are very homogenous and mostly focus on Celestial Motion and the Solar System (Planetary Sciences). In a sense, these areas of the curriculum are well served by AER and likely feed off each other - large groups of young humans mandated to learn about these topics in a relatively low stakes environment provide many opportunities for researchers to engage with these areas.

At the higher end of schooling, "Cosmology" becomes more prominent in the curriculum and has been growing significantly in AER in recent years (Salimpour, 2021). This is usually towards the upper end of high school so research on cosmology is more likely to overlap the old adolescent/young adult boundary between school curriculum and ASTRO101 and be more readily applicable across both groups. In contrast, approaches for "Celestial Motion" for elementary students and for young adults are significantly different. There is the "missing middle" problem where galaxies are missing from school-level research, but there is a chicken and egg problem here. It is not present in the curriculum (Salimpour et al., 2024) so it is not available as a research topic at this level as school populations who engage significantly with galaxy topics are rare.

Looking more broadly at what research is done compared to what is expected for astronomical literacy from the Big Ideas (BI) (Retrê et al., 2019), we see similar patterns. Celestial Motion (BI 2 & 3), Planetary Sciences (BI 7) and Cosmology (BI 6), Culture and History (BI 1) and Stars (BI 8) are well covered. Big Idea 4 attaches to many of the statements - "Light", "Scale and Size", "Computational Astronomy/Big Data" and "Instrumental/Techniques". The Big Ideas that are less well treated in comparison are the "missing middle" galaxy problem (BI 9), Astrobiology and Exoplanets (BI 10). Astrobiology is a frequent, but not ubiquitous, ASTRO102 or component of ASTRO101 and is relatively rare at school level so is less frequently studied. Exoplanets are a relatively new astronomical phenomenon and an area where students can engage directly with research (e.g., Kokori et al., 2022; Zellem et al., 2020), so will likely grow in the future. In conclusion, the Big Ideas are to some extent covered aside from the missing research on galaxies.

4.4 What is the general distribution of constructs used in AER?

Aside from general teaching - which could be a side effect of the commonality of ASTRO101-based research - the two most prominent constructs were "Content Knowledge", which is an understanding construct, and "Affective", which encompassed various affect constructs. "Engagement" which captures interactions between astronomy and society being the only construct - coming in third. The majority of other constructs are also more understanding focused.

Most of the affect-based constructs in the literature have been around general attitudes towards astronomy see (Bartlett et al., 2018). Recently, there have been some significant steps towards research in self-efficacy in astronomy (e.g., Bailey et al., 2017; Freed et al., 2022, 2023) as well as science identity (e.g., Colantonio et al., 2021), and attitudes/perceptions of the interaction between astronomy and other STEM disciplines (Salimpour, Fitzgerald & Tytler, 2024, in review). It is somewhat surprising that, given the oft-quoted statement that "Astronomy is a gateway science" - implying an affective change within an individual exposed to astronomy - that a variety of affective constructs beyond attitude have been so underrepresented thus far in the AER literature.

4.5 What is the general distribution of methodologies?

There is a rough balance between truly empirical research (~36%) and more general reporting (~43%) with somewhat less position papers or editorial style publications (~18%). There are understandably not too many literature reviews, but we do find very little theoretical research in the field nor many dealing with history of astronomy education research.

The ratio between mixed methods (~22%), qualitative (~11%) and quantitative research (~12%) is dominated by mixed methods. This represents that much research in the field of Astronomy Education Research is based in educational settings where it is possible to have both quantitative data and testing as well as deeper interviews, observations, and theoretical components to describe a rich learning environment. There is some indications that over the four eras, the field has turned from largely Quantitative to largely Mixed Methods. However, this should be interpreted with some caution – aside from small number statistics in earlier eras, as the "Mixed Method" idea itself only truly arose during the 1970s, sometime in the middle of Era 2 during the social science "Paradigm wars". Broadly as a field, AER does not appear to have a preference for one or the other broad type of research relying more on pragmatic decisions about what broad methodological approach answers the research question posed.

4.6 Recommendations and outlook for AER

After exploring the landscape of AER, we can see that there some areas that have a lot of research and others that do not. The fields that have been more frequently studied accounts for studies of children's perception and understanding of seasons, lunar phases, and the Sun-Earth-Moon, i.e. Celestial motions. Of course, we cannot say it to be studied too much or too little, but there is a clear risk related to what we previously mentioned, namely that researchers do not make proper literature reviews before starting a research project related to this Content category (Celestial motion). It may then become clear that many aspects of children's understanding already have been previously explored. This doesn't imply that Celestial Motion should not be researched, more that when it is, attending to the large and diverse literature first is highly recommended.

Considering those areas that have been less researched, almost any content related to astronomy outside the solar system and local stars and stellar populations is, in general, less researched. It is not surprising that there is not much research emerging out of school-level education research as it is not commonly in school-level education curriculum ((Salimpour et al., 2020, 2024)) which leads to minimal opportunities to research such topics. However, at the ASTRO 101 level many courses attempt to cover the full spectrum of objects in the universe and there are certainly examples of ASTRO 101 courses that focus specifically on stars and galaxies. Here, future astronomy education researchers have great opportunities to investigate new and almost entirely uncharted territories in AER until we get to the edge of the observable universe (Cosmology). In so doing they would be providing better understanding supporting ASTRO 101 undergraduate students' learning but also providing an evidence base to consider the inclusion, exclusion or relevance of such important astrophysics topics at the school-level.

There is one intermediate content that is interesting for the future, which bridges between different natural sciences by its nature, and that is Scale and Size. This interdisciplinary content is known to be a threshold concept for coming to understand science, and the universe, on a deeper level, hence deserves more attention from astronomy education researchers in the future.

Moreover, from the analysis we see that there seems to be only little international collaboration in AER; only some 4% of the publications indicate international collaborations. One can speculate on the cause of this, and one could be the language barrier. Since much AER aims at investigating school children's ideas and conception of the universe, making investigations in different countries would involve much work on translating materials and research data. On the other hand, as Salimpour et al. (2020) found, the curriculum in most of the OECD countries are similar, which in principle would make international collaborations, data collection, and analysis easy and straightforward and results comparable.

Concerning constructs and based on Figure 8, we see that disciplinary literacy and multidisciplinarity seem to be less researched and hence deserves more attention. In particular, and since astronomical literacy is seen as important by large organisations such as the IAU as well as a part of general science literacy by the majority of government and non-government science organizations, it would need more attention by researchers. When looking at target groups, we clearly see the domination by students of different ages. This is of course not surprising at all, since we are interested in how "we" - humans - come to understand the universe, and it is therefore natural to study young people and the learning processes involved. However, and for being able to even better promote learning about the universe, there is a particular group to focus on, namely the pre- and in-service teachers. This group of people, who are, or will be, the ones that educate the next generation should be of great interest for the AER community to study. They need to learn about all natural sciences, including astronomy, but usually they are only exposed to little, if any, astronomy during their teacher training. To make a difference for the future, studying the learning processes of this group, to be able to make recommendations for the future, is crucial for increasing the quality of children's understanding of the universe.

Summarising these findings, we recommend new astronomy education researchers to consider the findings presented here and also explore the iSTAR database when deciding on what to focus on in their research.

5 Conclusion

This paper has provided a descriptive overview of the AER English-language literature on a best-effort basis over all time up to 2022. We find that AER really "started" around 1970 and took off significantly around the 1990s with journal articles (~50%) and conference proceedings (~30%) being the most common method of publication. Early on, AER was largely a USA endeavour dominated by ASTRO 101 concerns.

This has changed over time and in recent years, the USA has dropped below 50% of the worldwide AER production. "Celestial Motion", "Earth", "Instrumentation/Techniques" (due to the rapid development in robotic telescope accessibility) and "Planetary Sciences (not Exoplanets)" top the content focus while in this paper we identify a significant lack of local galactic and extragalactic education research compared to opportunity. Aside from this, in a broad sense, the distribution of AER does follow the distribution of rates of teaching particular content although historically, "Celestial Motion" & "Earth" were much more dominant.

In terms of research topics, AER has been heavily focussed on "Content Knowledge", "Affective", and "Engagement". In terms of methodology, we find that most articles tend to be general reporting (~43%) rather than full empirical research (~36%) while there is very little theoretical or historical research in AER and that most approaches are mixed methods in the current era but historically were more quantitative.

6 Declarations

6.1 Ethical Approval

This study did not use human subjects.

6.2 Consent for Publication

All authors have consented to this publication.

6.3 Competing Interests

The authors are editors of the journal, and as such the review process was allocated to an editorial board member to ensure double-blind anonymous peer-review.

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