Examining the mismatch between the intended astronomy curriculum content, astronomical literacy, and the astronomical universe

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Over the years, there have been various calls to increase and better represent astronomy in curricula. This is motivated by views within the astronomy and astronomy education communities that the awe, wonder, and interdisciplinary nature of astronomy has the potential to engage students in STEM across disciplines. Reviews of curricula have shown that astronomy topics are represented in most mandated curricula around the world and although there is a homogeneity of astronomy topics in most mandated curricula, this representation has its limitations. By using the Australian National Curriculum, the USA-based Next Generation Science Standards (NGSS), and the Swedish National Curriculum as examples, this study unpacks ideas around "How much astronomy is enough?", the mismatches between astronomy topics in curricula and what constitutes astronomical literacy within the context of the Big Ideas in Astronomy document. The results identify that there is a significant gap at the galactic and extragalactic scales when considering the typical progression of astronomy topics when considering the conceptual, spatial, and temporal scales of the topics. Specifically, topics in curricula jump from tangible concepts within the student's immediate and Solar System spatial scales in primary school to cosmological spatial scales in upper high school, without reference to spatial and conceptual connecting topics at galactic scales. Potential sample curriculum statements drawn from the Big Ideas are presented as a suggested curriculum inclusion. This curricula gap is identified as a potential source of a similar gap in education research in these topics at these levels, which in turn perpetuates the problem by there being a lack of research-based evidence for inclusion in the curriculum.

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I. INTRODUCTION

Over the past few decades, astronomy education research (AER) has been gaining momentum and presence [1–3]. This interest is owed in part to astronomy providing students with an attractive "gateway to science" [4], STEM in general [5], and a fertile ground for teaching large numbers of early undergraduate students in terminal "astro101" courses [6–11]. The general focus of the field of AER tends to be less on training more astronomers and rather on facilitating students to appreciate science and their place in the universe [12–14].

Although much of AER has been focused on astro101 courses primarily taught in the United States [15], the focus of this manuscript is precollege or university level (K-12). The reason for this is that research shows topics in astronomy are prevalent in most school curricula [4]. Furthermore, there is "no specific curriculum" for astro101, unlike the school system. It is also the case that it is only in the United States and Canada that astro101 courses for non-science majors are common. They certainly do exist in other countries [16] but on a dramatically smaller scale and usually for a combination of both majors and nonmajors. It is commonly claimed in the AER literature that astro101 is the "last course students may ever take in science." However, in most of the rest of the world, the last mandatory science

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course students ever take tends to be in roughly year 10 of formal schooling [16], with science in the last 2 years of schooling primarily preparing students intending to major in STEM-related disciplines at university in the "Big Three" topics (Physics, Chemistry, and Biology). Hence, from a global perspective, the astronomy content of the school science curriculum is usually the only entry and influence we have into formal education for a large-scale population. This is certainly true also for the many North American citizens who do not enter into the tertiary environment.

It should be emphasized that this current research focuses on the intended curriculum, as an initial step of scoping the landscape, before exploring the implemented curricula. Even though, in the majority of cases, the intended and implemented curriculum is different, it is the intended curriculum that teachers use to inform their teaching and that school administrators perceive as important. We argue based on our experience developing curricula at the national level and teaching in classrooms that if a topic is not perceived as important, it is far less likely to make it into the implemented curriculum. Furthermore, intended curricula in some countries are more guidelines or frameworks, which teachers can choose to interpret within the parameters set by the relevant local school board.

Assuming, in a perfect world, every curriculum developer decides to incorporate astronomy into their respective curricula, the question then arises: "What to include?". In 2019, the astronomy education community released the *Big Ideas in Astronomy: A Proposed Definition of Astronomy Literacy* [17]. This document brings together 11 Big Ideas and 97 associated subideas in astronomy that cover the current state of knowledge or rather "What should science-educated citizens know about astronomy?". These Big Ideas cover various themes in astronomy and serve as a guide for developing curricula, lessons, and/or units in astronomy. They are not meant to be curriculum statements or even a curriculum. One aspect of the Big Ideas document is that it is dynamic and constantly updated to include more recent groundbreaking concepts in astronomy.

The work presented in this paper is intended for a range of audiences, which includes researchers, curriculum developers, teachers, and policymakers. In order to develop curricula that meet the needs of students and the context, it is necessary for all these audiences to have a snapshot of the curriculum landscape from various different lenses. For researchers, this study provides them with insights into the gaps and limitations of the current landscape. This helps inform deeper research into curricula, which support the development of curriculum by developers. For teachers, having a study that is tangible to their teaching, allows them to appreciate how they can contribute to the discourse about curriculum in a way that is informed by research. For policymakers, having big-picture studies that have identified strengths, weaknesses, and opportunities allows them to support changes at a national level.

Having said this, we must also acknowledge that there are broader forces at play in the shaping of curricula around the world that have little to do with just content. We explicitly are not dealing with those parts of the curricula that deal with skills, interdisciplinary approaches, or science as a human endeavor, which we do address in other research. In essence, considering those aspects of the curriculum perhaps highlights the interconnectivity between disciplines and how they can perhaps be integrated through astronomy as a context. In this paper, we focus just on the content knowledge that should be included. There are broader political, cultural, religious, and economic factors that do drive actual curriculum development beyond the more straightforward comparisons of curriculum content that we consider here. We acknowledge that we are focusing on one piece of the curriculum puzzle in this paper. However, we will suggest that there are important missing aspects to this particular puzzle piece.

There is also an interesting feedback mechanism between curricula and education research. In producing this research, it would be very useful to introduce all of the research that has been undertaken at the school level for certain topics. However, if the topics are not in the curriculum, then they generally are not taught at all at any significant scale. If they are not taught, then there are no students, teachers, or schools upon which to undertake research. For those parts of the curriculum that are not taught, there is also a corresponding lack of research on these topics (see Ref. [15]). Without this research base, there is a lack of evidence to convince curriculum developers to explore beyond existing, generally largely replicated, curricula. This is potentially one reason astronomy topics in curricula are quite homogenous around the world [4]. Research into K-12 curriculum areas that are not taught but potentially should be is very important but missing from the current research literature.

In order to better characterize the astronomy topics or content in curricula, this study explored the question: Do current intended astronomy curricula over the course of mandatory schooling (K-12) cover the appropriate astronomical content areas necessary for astronomical literacy as outlined by the "Big Ideas"? If not, what needs to be included?

This study begins by exploring the current state of astronomy topics in the intended curricula and the question of "how much is enough"? Following this, an overview of the Australian National Curriculum (ANC), the USA-based Next Generation Science Standards (NGSS), and the Swedish National Curriculum (SNC) are provided in the context of astronomy topics. This provides three typical curricula to explore, owing to the homogeneity in the occurrence of astronomy topics in intended curricula [4] and the broader studies on larger numbers of national curricula elsewhere [18].

II. METHODS

This study used a mixed-methods approach to explore the curriculum statements from ANC, NGSS, and SNC. Each curriculum was read and the statements that specifically addressed astronomy topics were extracted for each year level. We did not focus on statements that "could be related" to astronomy as this would create a level of complexity that can only be unpacked in the context of the implemented curriculum. As noted earlier, the focus was also on the astronomical content knowledge rather than the associated general skills or interdisciplinary approaches. Once the statements were extracted, the authors went through and coded each statement according to the spatial and temporal scale. This coding was iteratively refined through author discussions to create the spatial and temporal layers in astronomy visualized in Figs. 2 and 3.

III. ASTRONOMY IN THE INTENDED CURRICULA

A recurring theme in the astronomy and astronomy education communities is to work toward putting more astronomy into the formally mandated curriculum. The debate about including astronomy in the curriculum is not new [19–21]. This is in response to the general statement that astronomy is not present in the curriculum. This statement has two interpretations: (i) That there are no astronomy topics present; or (ii) that astronomy as a stand-alone subject is not present.

Examining the first interpretation, that astronomy topics are not present in the intended curriculum, we find this to not be true. Research has shown that at least across the Organization for Economic Cooperation and Development (OECD) countries, China and South Africa, there are astronomy topics present in some form [4]. A more recent review that covers over 70 countries, 18 of which are OECD countries, has revealed a similar distribution [18]. There is also a certain level of homogeneity in the topics that are addressed and the year levels at which they are addressed. For example, they focus broadly on celestial motion in elementary or primary school, the planets and the Solar System in middle school, and then jump over a vast conceptual and spatial gap into cosmology in high school.

Examining the second interpretation, that astronomy as a stand-alone mandatory curriculum subject is rare. This is largely true, although, there are a few instances of astronomy as an elective subject (∼67%) or as its own subject in middle and high school, such as in Thailand [18]. The likely scenario is that most curriculum design panels do not consider having astronomy as a mandated stand-alone subject to be an efficient use of the "curriculum space."

Upon consideration, it could be immediately and validly argued that if astronomy has its own subject, then its natural stablemate—Earth Science—should also. We see this in actual curricula such as the Australian National Curriculum [22] and the USA-based Next Generation Science Standards (NGSS) [23], both of which incorporate astronomy under the content area of Earth and Space Sciences. It is the combination of Astronomy and Earth Science together with non-STEM disciplines that is necessary to understand and address the current "wicked problem" [24] of the era—climate change. This is evident with the proactive move by astronomers to contribute to providing better information about climate change [25]. An argument could be made that, due to their importance, Astronomy and Earth Science should be expanded in the curriculum. If so, then the next question becomes—"which subject(s) or topics should be removed to prevent overloading the already overloaded intended curriculum?" It would be unlikely to be cut from the "Big Three" (Physics, Biology, or Chemistry). This is, then, the actual case in which we find ourselves. Science, particularly in high school, is dominated by the Big Three (Physics, Biology, and Chemistry) with a smattering of Earth, Space, and, in some countries, Environmental Sciences which combine elements of all five of the previous content areas [22,23].

Furthermore, recent work [26] and anecdotal evidence question whether the quest to include more astronomy content in the curriculum is justified. Perhaps, the goal should be how to maintain interest in astronomy beyond the classroom. More importantly, even the question of including more astronomy in the curriculum is still up for debate and perhaps not shared by all members of the astronomy education community.

A. How much astronomy is "enough"?

Studies reveal that most nations around the world have astronomy topics in their intended curriculum [4,18]. This does not even include countries that offer elective studies in astronomy, which vary from school to school and are, in most cases, at the discretion of the teacher. However, some curricula have Astrophysics as an optional topic, for example, the United Kingdom O and A levels. In this paper, we provide an overview of three curricula, the Australian National Curriculum (ANC), the Next Generation Science Standards (NGSS), and the Swedish curriculum as typical examples to use as a data source.

Looking at the ANC, NGSS, and Sweden, we extracted all the statements for each of Biology, Chemistry, Physics, Earth and Space Sciences, Astronomy, and Engineering/Technology. This allowed for a quantitative measure of the occurrence of each domain to be visualized (Fig. 1). This was done for grades 1–10, as this is usually the range where science is a mandatory part of the curriculum. It can be seen from Fig. 1 that astronomy forms a small percentage of the curriculum relative to the other domains. At first glance, this can be seen as the reason to include "more astronomy in the curriculum," but we see this as an opportunity to use astronomy as a context to build connections with the "major domains."

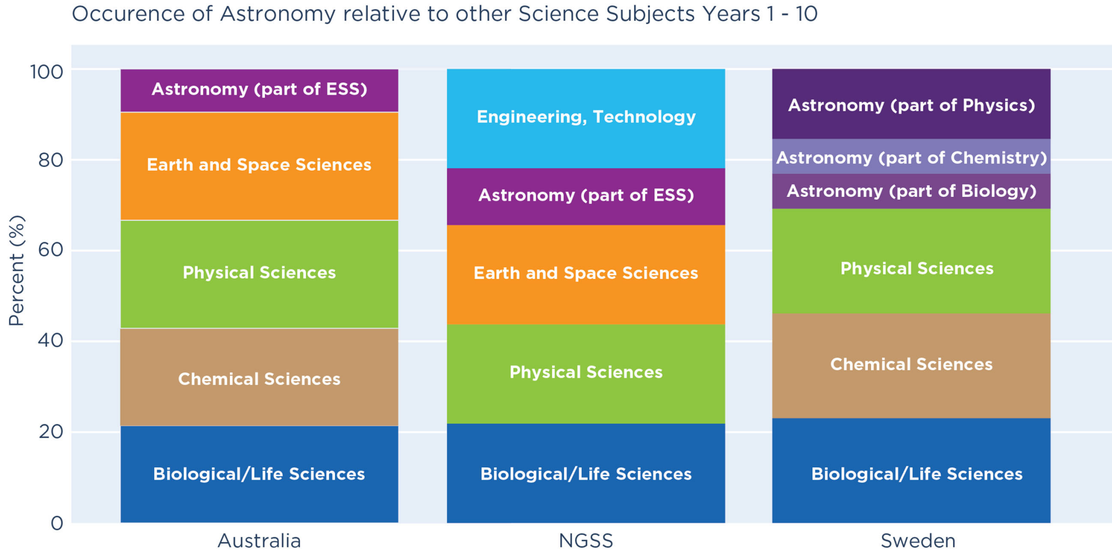

FIG. 1. The relative occurrence of astronomy compared to other science subjects for grades 1–10. It should be noted that in the NGSS, we used the discipline rather than disciplinary core idea as the overarching parameter, so it seems that the NGSS is missing Chemical Sciences, but in fact, Chemical Sciences is located under Physical Sciences. The Swedish curriculum includes Earth Science in the Geography subject which is covered under the overarching topic of Social Studies. Although astronomy is a small percentage, the fact that it has connections with all the sciences affords the opportunity to use it as a context to teach the other sciences.

IV. SPATIAL AND TEMPORAL LAYERS IN ASTRONOMY

Astronomy has a relatively unique setup as a content topic because, to a very real extent, *everything* is astronomy, in that it can be connected readily and directly to both STEM and non-STEM disciplines. Astronomy is the study of the universe as a whole and, as the universe contains the planet Earth and everything on it and in it, including ourselves. Astronomy brings together everything generally considered in the school curriculum. Traditionally, however, we consider astronomy largely encompassing things that happen "in and beyond the sky." There are some clearly identifiable conceptual scales within the universe where different phenomena appear, different processes occur, and different concepts need to be considered. In a perfect world, the expectation would be that a fully educated student in science would have a conceptual picture of each layer, even if that picture is somewhat trivial or marginally flawed.

The development of the spatial and temporal layers in astronomy was done by carefully considering the Big Ideas in Astronomy document [17], and curriculum statements [4], also drawing on the various research on learning progressions [12,27–30]. The Big Ideas document was developed through an extensive iterative process involving astronomers, teachers, education researchers, and members of the broader astronomy community. The first stage involved the development of overarching ideas that captured the "knowledge" science-informed citizens would be expected to know about astronomy concepts.

These overarching themes were refined through an iterative process: the Night Sky, History, Society, Instrumentation, Stars, Galaxies, Cosmology, Planets, Milky Way, Earth, and Beyond the Solar System. For each of the themes, statements were developed that captured the essence of the concepts. For example: "(6) Cosmology is the science of exploring the Universe as a whole," or "(2)

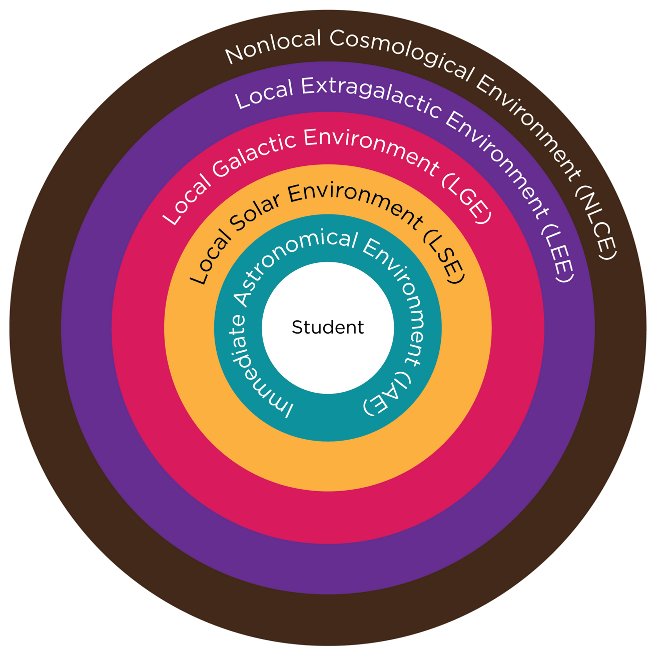

FIG. 2. The gradual progression in terms of spatial and temporal relations when thinking about concepts in astronomy. This progression places the student at the center where concentric rings represent a progression in spatial and temporal scales. These rings although demarcated do in fact overlap to a certain degree. This is where it is important to have a progression in ideas, rather than isolated disjointed cases.

Astronomical phenomena can be experienced in our daily lives.”. These overarching statements were then used to generate the various fine-grained subideas that captured some of the key concepts encompassed by the statement, for example, “(2.1) We experience day and night because of Earth’s rotation around itself” or “(6.3) The Universe is mainly composed of Dark Energy and Dark Matter.”

Next, each subidea was elaborated with a brief explanation of the key concepts that explained the subidea. Members of the astronomy community (both from within the International Astronomical Union and beyond), which included astronomers, astronomy educators, and astronomy education researchers, were invited to provide feedback. This feedback process was transparent and public so it involved rich discussions.

The curriculum statements and Big Ideas were then categorized based on scale, and these were then combined into overarching scales. These layers are represented in Figs. 2 and 3 and we briefly define each layer below.

The *Immediate Astronomical Environment (IAE)* has the most fluid graduated boundary. At the ground where we stand, if we move out toward space, we first begin in the atmosphere, the topic for “Atmospheric Science.” At some tens of kilometers above the ground, we start transitioning slowly into the arena for “Space Science,” the border of which changes as our spacecraft becomes more capable. The most useful cutoff for this layer is just before hitting the Moon, see Figs. 2 and 3. This we define as the “Immediate Astronomical Environment.” Much of this layer overlaps with many other sciences and also nonsciences. Within this is included phenomena and knowledge relating to the direct human perception of the night sky and its patterns, such as the seasons, weather, moon, and planets and their impacts on human activity and culture.

The *Local Solar Environment (LSE)* starts at the edge of the IAE and moves through to the heliopause, where the Sun’s influence no longer dominates. Many of the concepts in these layers are—or at least can be—directly experienced by students, such as the seasons, planetary motions, planets, comets, etc. There can also be overlap between LSE and IAE when teaching a given concept, e.g., the Moon’s apparent motion and shape change across the sky is an IAE topic—an immediately direct experience whereas the orbit of the Moon and its relation to the sun is an LSE topic—an abstraction of the position of the Earth-Sun-Moon system beyond the IAE.

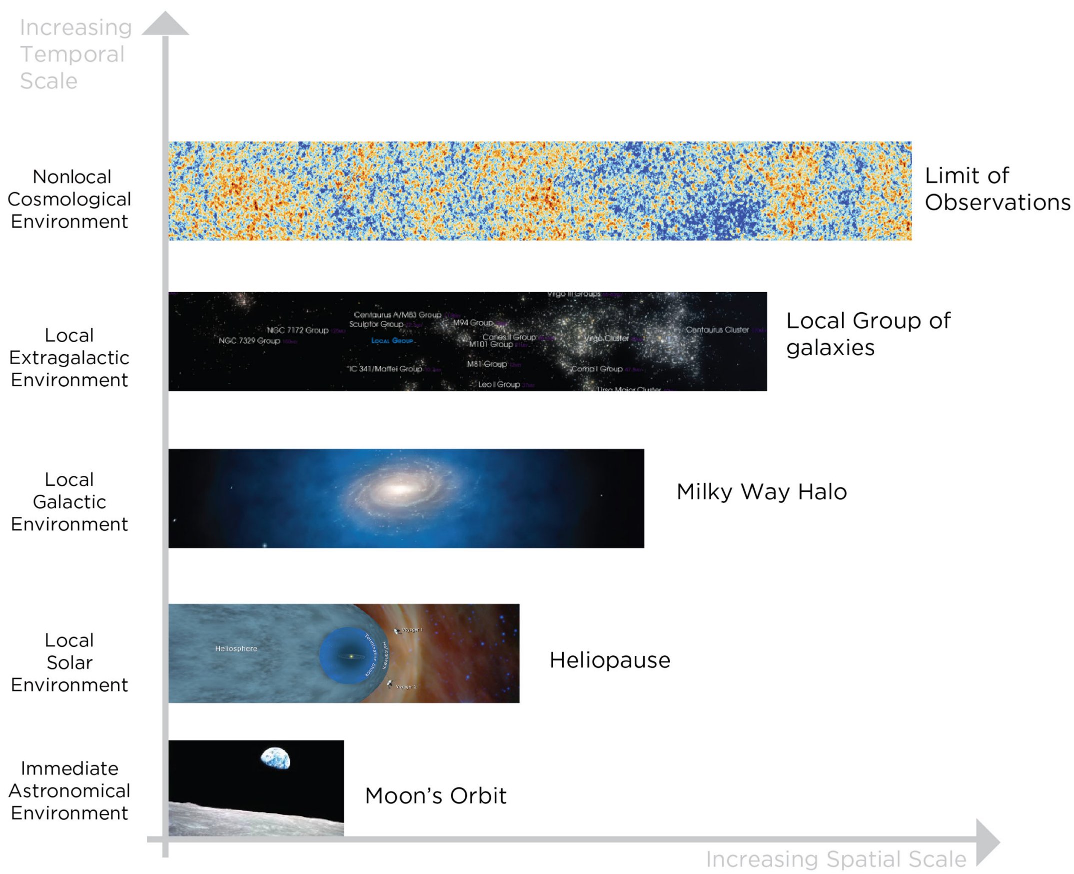

FIG. 3. A representation showing the layers from Fig. 2 and the blurry limits of each one. It should be noted that the layers not only represent increasing spatial but also increasing temporal scales due to the light travel time—lookback time. Images credit: NASA, ESO, Planck, ESA.

The *Local Galactic Environment (LGE)* describes the nearby environment around the Sun and its various objects and organization. Topics include the local Solar neighborhood of stars, the size and shape of the galaxy and its spiral arms, and the components of the galaxy, such as stars, exoplanets, nebulae, star-forming regions, and clusters among other objects. It is this layer that has the richest array of objects and concepts, yet it is the most neglected as we shall see later.

The *Local Extragalactic Environment (LEE)* looks at the Milky Way and the galaxies that surround it. This layer includes the types of galaxies in the universe and how they are arranged in smaller clusters.

The *Nonlocal Cosmological Environment (NLCE)* looks at how galaxies are distributed on larger scales and throughout the whole universe, ending with the edge of the observable universe. This layer, due to the relationship between distance and time in the universe, also includes the evolutionary history of the entire universe.

V. SNAPSHOT OF THREE CURRICULA

A. Australian National Curriculum

The previous iteration of the Australian National Curriculum F-10 v8.4 [31] included astronomy content mainly as part of the science learning area, under the heading Earth and Space Sciences, encompassed by the strand Science Understanding. In 2022, the Australian National Curriculum was updated (Table I), and there were changes made to link content across disciplines, and to better incorporate cultural perspectives. Astronomy concepts or topics in the revised national curriculum are present in Years 2, 6, 7, and 10. In addition, we see aspects of astronomy appearing under the science inquiry strand.

B. Next Generation Science Standards

The Next Generation Science Standards (NGSS) is the reformed curriculum adopted by 18 states in the United States [23]. The standards were released in 2013 and bring

TABLE I. Australian National Curriculum F-10 v9, curriculum statements, and Elaborations for Earth and Space Sciences. Each of the curriculum statements has been mapped to the Astronomical Scale (Fig. 4), which is explained in the next section, and the Big Ideas in Astronomy [17].

Level	Statement	Elaborations	Astronomical scale	Big ideas
Year 2	Recognize Earth is a planet in the solar system and identify patterns in the changing position of the Sun, Moon, planets, and stars in the sky	Identifying celestial objects that can be observed in space such as the Sun, Moon, stars, and planets	IAE, LSE	2, 3
		Viewing images or video of Earth from space, describing the shape of Earth and discussing how the images or video were taken	IAE	11
		Exploring representations of the solar system and identifying Earth and other planets	LSE	7
		Observing that some phenomena in the sky are only visible during the day and others during the night	IAE	2, 3
		Investigating how shadow length changes with the changing position of the Sun, identifying patterns, and making predictions	IAE	2, 3
		Creating a class moon diary across a month, identifying patterns in the changing shape of the moon, and making predictions	IAE	2, 3
		Viewing a time-lapse video of the Sun, Moon, stars, or a satellite's movement across the sky	IAE	2, 3
		Observing and describing short-term and longer-term patterns of events that occur in the sky, such as the appearance of the moon and stars at different times of the month or year	IAE	2, 3
		Distinguishing between regular events that occur in the sky, such as the appearance of a full moon, and irregular events such as blue, blood, or super moons	IAE	2, 3
		Exploring how cultural stories of First Nations Peoples of Australia describe the patterns in the changing positions of the Sun, Moon and stars	IAE	1

(Table continued)

TABLE I. *(Continued)*

Level	Statement	Elaborations	Astronomical scale	Big ideas
Year 6	Describe the movement of Earth and other planets relative to the Sun and model how Earth's tilt, rotation on its axis, and revolution around the Sun relate to cyclic observable phenomena, including variable day and night length	Exploring simulations of the solar system such as a pocket solar system to appreciate the distances and relationships between the Sun and planets	LSE	4, 7
		Recognising the role of gravity in keeping the planets in orbit around the Sun	LSE	7
		Using 3-dimensional models or role-play to model how Earth's rotation on its axis causes day and night	IAE, LSE	2, 3
		Using virtual simulations or real-time views of Earth from space to explore why different regions on Earth, such as the South Pole, experience long periods of sunlight or darkness over the cycle of one revolution of Earth around the Sun	IAE	2, 3
		Using 3-dimensional models to explore how the tilt of Earth points one hemisphere towards the Sun and the other away at different times of the year, and predicting how this affects the amount of sunlight on the surface of different regions on Earth	IAE, LSE	2, 3
		Researching First Nations Australians' understandings of the night sky and its use for timekeeping purposes as evidenced in oral cultural records, rock paintings, paintings, and stone arrangements	IAE	1
Year 7	Model cyclic changes in the relative positions of the Earth, Sun, and Moon and explain how these cycles cause eclipses and influence predictable phenomena on Earth, including seasons and tides	Using physical models or virtual simulations to explain how Earth's tilt and position relative to the Sun causes differences in light intensity on Earth's surface, resulting in seasons	IAE, LSE	2
		Examining the effect of the gravitational attraction of the Moon and the Sun on Earth's oceans and describing how the relative positions of the Moon and Sun with respect to Earth result in tidal variations	IAE, LSE	2
		Using physical models or virtual simulations to explain the cyclic patterns of lunar phases and eclipses of the Sun and Moon	IAE, LSE	2
		Researching knowledges held by First Nations Australians regarding the phases of the Moon and the connection between the lunar cycle and ocean tides	IAE	1, 2
		Investigating First Nations Australians' calendars and how they are used to predict seasonal changes	IAE	1, 2
		Researching First Nations Australians' oral traditions and cultural recordings of solar and lunar eclipses and investigating similarities and differences with contemporary understandings of such phenomena	IAE	1, 2

(Table continued)

TABLE I. *(Continued)*

Level	Statement	Elaborations	Astronomical scale	Big ideas
Year 10	Describe how the big bang theory models the origin and evolution of the universe and analyze the supporting evidence for the theory	Describing the major components of the universe using appropriate scientific terminology and units including astronomical units, scientific notation and light-years	NLCE	Mixed
		Constructing a timeline to show major changes in the universe which are thought to have occurred from the Big Bang until the formation of the major components such as stars and galaxies	NLCE	6
		Examining how stars' light spectra and brightness is used to identify compositional elements of stars, their movements and their distances from Earth	LGE	4, 8
		Explaining how each different type of evidence, such as cosmic microwave background radiation, red or blue shift of galaxies, Edwin Hubble's observations, and proportion of matter in the universe, provides support for the acceptance of the big bang theory	NLCE	6
		Researching First Nations Australians' knowledges of celestial bodies and explanations of the origin of the universe	IAE	1, 6
		Identifying the different technologies used to collect astronomical data and the types of data collected	N/A	5
		Exploring recent advances in astronomy, including the Australian Square Kilometre Array Pathfinder, and astrophysics, such as the discovery of gravitational waves, dark matter, and dark energy; and identifying new knowledge that has emerged	N/A	4, 5

together the three dimensions—Crosscutting; scientific and engineering practices; and disciplinary core ideas—highlighted in the document "A Framework for K-12 Science Education" [32]. Looking at the standard content related to astronomy is found in Earth and Space Sciences (ESS) and Space Systems (Table II).

C. The Swedish National Curriculum

The Swedish National Curriculum (SNC) [33,34] was revised in 2018, it includes topics in astronomy within the three sciences of Biology, Chemistry, and Physics (Table III).

TABLE II. Astronomy content in the NGSS curriculum.

Level	Statement		Astronomical scale	Big ideas
Grade 1	ESS1: Earth's Place in the Universe	ESS1.A: The Universe and its Stars *(1-ESS1-1): Patterns of the motion of the Sun, Moon, and stars in the sky can be observed, described, and predicted.*	IAE	2, 3
		ESS1.B: Earth and the Solar System *(1-ESS1-2): Seasonal patterns of sunrise and sunset can be observed, described, and predicted.*	IAE	2
Grade 5	ESS4: Earth's Place in the Universe	ESS1.A: The Universe and its Stars *(5-ESS1-1): The Sun is a star that appears larger and brighter than other stars because it is closer. Stars range greatly in their distance from Earth.*	LSE	8
		ESS1.B: Earth and the Solar System *(5-ESS1-2): The orbits of Earth around the Sun and of the Moon around Earth, together with the rotation of Earth about an axis between its North and South poles, cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the Sun, Moon, and stars at different times of the day, month, and year.*	IAE, LSE	2, 3

(Table continued)

TABLE II. *(Continued)*

Level	Statement		Astronomical scale	Big ideas
Middle School	MS-ESS1: Earth's Place in the Universe	ESS1.A: The Universe and Its Stars *(MS-ESS1-1): Patterns of the apparent motion of the Sun, the Moon, and stars in the sky can be observed, described, predicted, and explained with models.*	IAE, LSE	2, 3
		(MS-ESS1-2): Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe.	LSE, LGE	9
		ESS1.B: Earth and the Solar System *(MS-ESS1-2),(MS-ESS1-3): The solar system consists of the Sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them.*	LSE	7
		(MS-ESS1-1): This model of the solar system can explain eclipses of the Sun and the Moon. Earth's spin axis is fixed in direction over the short term but tilted relative to its orbit around the sun. The seasons are a result of that tilt and are caused by the differential intensity of sunlight on different areas of Earth across the year.	IAE, LSE	2, 3
		(MS-ESS1-2): The solar system appears to have formed from a disk of dust and gas, drawn together by gravity.	LSE	7
High School	HS-ESS1: Earth's Place in the Universe	ESS1.A: The Universe and Its Stars *(HS-ESS1-1): The star called the Sun is changing and will burn out over a lifespan of approximately 10 billion years.*	LSE	8
		(HS-ESS1-2),(HS-ESS1-3): The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.	LSE, LGE	4, 8
		(HS-ESS1-2): The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.	NLCE	6
		(HS-ESS1-2), (HS-ESS1-3): Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.	LGE	6
		ESS1.B: Earth and the Solar System *(HS-ESS1-4): Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the Sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.*	LSE	7
		(HS-ESS1-6): Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the Solar System, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.	IAE, LSE	7, 11

TABLE III. Astronomy content in the Swedish National Curriculum.

Level	Subject	Statement	Astronomical scale	Big ideas
Years 1–3	Science	Seasons of the year in nature		
		• Motion of the Earth, Sun, and Moon in relation to each other.	LSE	2, 3
		• Different phases of the Moon.	IAE	2
		• Constellations and the appearance of the sky at night during different seasons of the year.	IAE	2

(Table continued)

TABLE III. *(Continued)*

Level	Subject	Statement	Astronomical scale	Big ideas
Years 4–6	Physics	Physics and world views		
		• The planets of the Solar System and their motion in relation to each other. How day, night, months, years, and seasons can be explained.	IAE, LSE	2, 7
		• Man in space and the use of satellites.	IAE	11
		• Measuring time in different ways, from sundials to atomic clocks.	IAE	2
Years 7–9	Physics	Physics and world views		
		• Scientific theories about the origins of the universe in comparison with other descriptions.	NLCE	1, 6
		• Development of the universe, the occurrence of atoms, development of the stars.	NLCE	6
		• Structure of the universe with planets, solar systems, and galaxies, and also their movements and distances between them.	LSE, LEE	6, 7, 9

VI. ASTRONOMY CURRICULA CONTENT CHASM

Looking at the examples above and comparing these to intended curricula around the world [4], there is a particular disjoint between some very local (at least in a cosmological sense) astronomical phenomena such as the Solar System, the night sky, the seasons, and very nonlocal—the cosmological—at higher year levels. In Fig. 2, we show the various spatial levels of astronomical phenomena as color-coded layers. Looking back on Tables I–III, the curriculum statements have been labeled as to where they fit in the spatial and temporal layers as shown in Fig. 2. For many intended curricula, there is quite a giant leap to go from the quite familiar experiences (the night sky, seasons, Jupiter) to the quite abstract (the Big Bang).

If we examine the curricula in Tables I–III, and visualize the distributions, the "missing area" in the astronomy curriculum worldwide—ANC, NGSS, and Sweden being typical examples—is generally the local galactic and extragalactic environment (Figs. 4 and 5). These are the

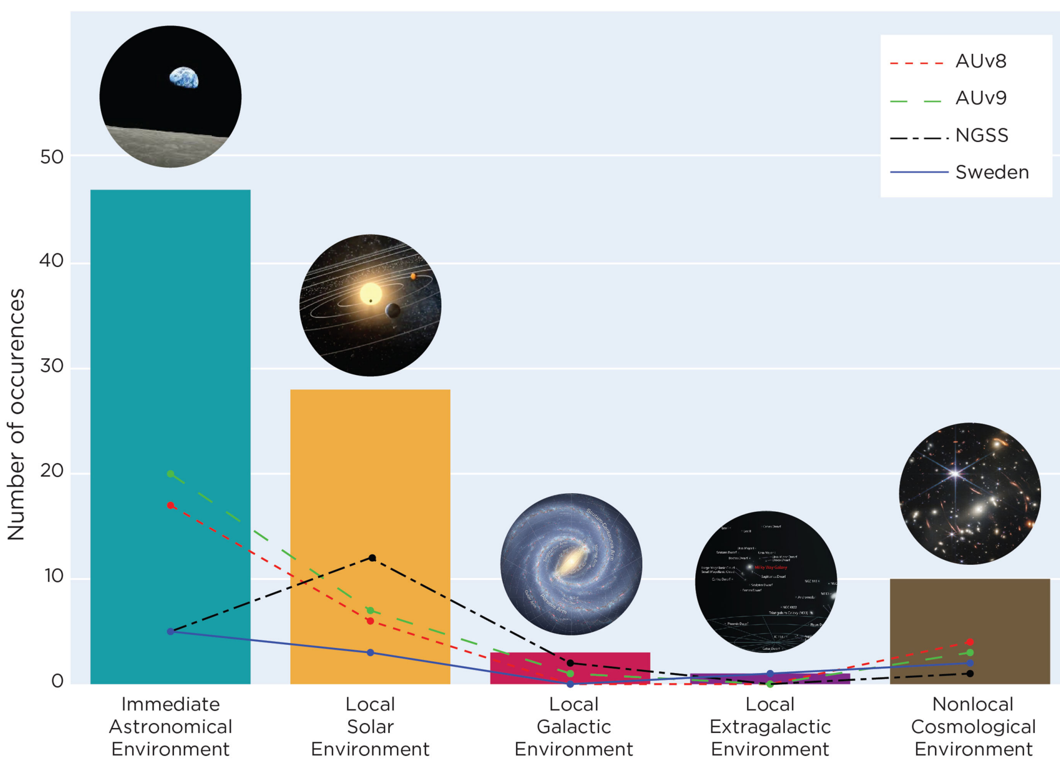

FIG. 4. Visualization showing the distribution of the layers for each of the curricula. The lines on the visualization represent the number of occurrences for the different astronomical scales for each of the four curricula. Superimposed are images representing the various scales.

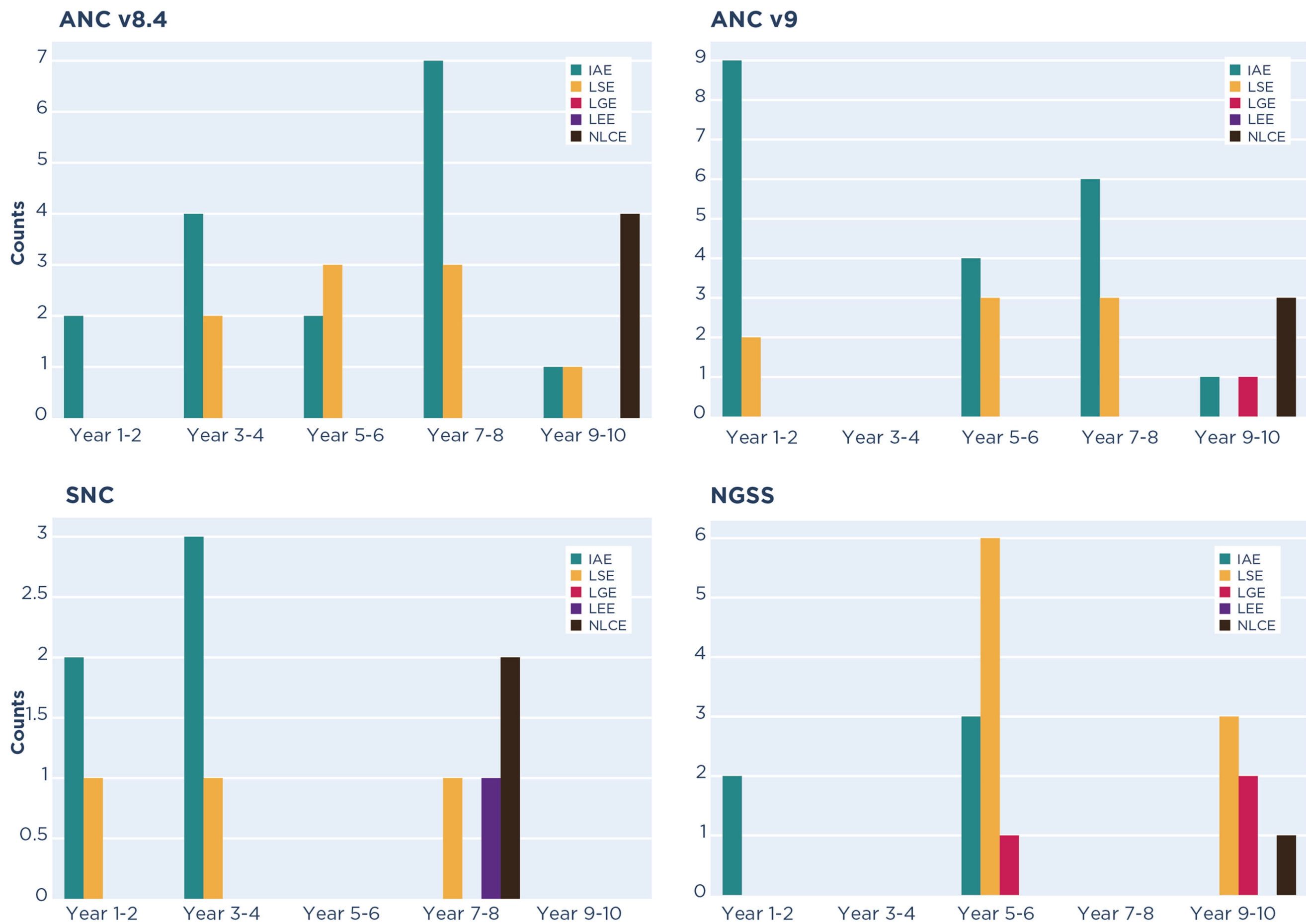

FIG. 5. Visualization showing the distribution of the layers for each year-level group for all four curricula—ANC v8.4, ANC v9, NGSS, SNC.

conceptual ideas that we are in the Milky Way Galaxy, that there are stars as well as other solar systems nearby and that there are galaxies in the "immediate vicinity" beyond the Milky Way. This is the "content chasm" between the largely local elementary and middle school levels and the leap to cosmology at the upper levels. In a sense, students go from quite direct experience and get launched into the abstract large-scale universe too quickly. While we do not present compelling evidence for why this might be the case here, it would not be an unreasonable hypothesis that, given the relative homogeneity of astronomy curricula around the world, this is a result of the 1960s or 1970s era of curriculum reform—driven by NASA—in an era where these areas in astronomical science were less well understood [35].

On the other side of the coin, to fully grasp some of the topics—seasons being a good example—requires higher mathematical skills, such as trigonometry, area, and flux compared to the incident angle, that are only really dealt with in later high school. The relatively descriptive (at this schooling level) approach to the local Galaxy environment is much easier to get a conceptual handle on. Seasons are trickier, and galaxies are simpler than many curricula imply.

When thinking about this progression, it helps to have a guide on the various overarching concepts that encompass the "basic" concepts in astronomy across these large spatial and temporal scales. This is where the Big Ideas in Astronomy document [17] can be used to inform the progression of astronomy concepts in curricula.

VII. DISCUSSION

A. Perspectives on curriculum statements

Looking at the curriculum statements in general, there exist misconceptions in the statements. This has been shown in Salimpou *et al.* [4] within the context of the OECD, and more recently in Ref. [18]. This is particularly concerning because teachers rely heavily on the curriculum, especially if they are not familiar with the content themselves. We present two examples below from the ANC.

Furthermore, curriculum statements, in general, tend to focus on the "facts" of astronomy and are often media-hyped statements. In the ninth version of the ANC at year 2, we have the statement: "distinguishing between regular events that occur in the sky, such as the appearance of a full moon, and irregular events such as "blue," "blood," or super' moons." This statement is an example of the use of misleading terms that do not emphasize the underlying physical and conceptual mechanisms leading to the appearance of the Moon. The terms blue, blood, or super assume students understand the fundamentals of relative scales, relative motions, complex cycles, and light scattering effects. These fundamentals are not taught in year 2, so using these terms can create alternative conceptions with research showing that when established, they are persistent and hard to change [12,36,37]. An appropriate version of this statement could be: "distinguishing between various events that occur in the sky, such as the appearance of a Full Moon." This statement gives the teacher the opportunity to be flexible to explore the various events conceptually rather than some definitions that have no relation to the underlying concepts.

A different example, which directly relates to a teaching approach, rather than a content concept, is the statement in year 7: "exploring simulations of the Solar System such as a pocket Solar System to appreciate the distances and relationships between the sun and planets." The pocket Solar System was introduced by one of the authors in Australia a few decades ago; however, the wording of the statement is very prescriptive and inaccurate. The pocket Solar System is actually a model or rather representation [38,39]. The statement could perhaps read: "Using a range of representations and scale models to support students in appreciating the relative distances and sizes between the Sun and planets in the Solar System." The fact is that astronomy education drawing on science education research in the context of representations has shown that students need to construct, use, and interrogate a range of representations to understand the complex and intangible spatial and temporal relations, the reason is that a single representation only conveys part of the "picture" [12,40]. Therefore, the curriculum statements should provide teachers with the opportunity to use a range of representations to support students in exploring the various aspects of a concept. Furthermore, this statement is particularly important when it comes to the challenges with regard to 3D and 3D representations in astronomy [41].

B. Progression of topics

The revised Australian National Curriculum brings together content and cultural dimensions of astronomy and has to a certain degree established limited connections between disciplines. However, the presence of astronomy in the curriculum is not based on a progression in concepts. Students encounter the Sun and the Moon in year 2, but there is no instance of it until year 6 and 7 where they learn a bit more about the Sun and the Moon, and some of the Solar System, and then a big jump to the edge of the observable universe with extragalactic cosmology in Year 10 with no great mention of the things in-between such as "stars" and "galaxies" and "extra-solar planets" among others.

The notion of learning progressions in astronomy education and education in general is quite powerful [29,42–44]. Learning progressions are not curriculum statements but rather a roadmap on how to scaffold students toward developing a robust conceptual understanding of given concepts. Given the complex nature of topics in astronomy and the intangibility of spatial and temporal relations, it is vital to have a guide on how students reason at different levels of sophistication, a progression not only in knowledge but also in reasoning. This has been highlighted in the context of cosmology education [45–47], whereby student reasoning was mapped to the SOLO (Structure of the Observed Learning Outcome) Taxonomy [48], which led to the development and validation of a concept inventory, which focuses on student's conceptual understanding of cosmology in school. Therefore, curricula that aim to effectively incorporate and leverage the potential of astronomy need to take into consideration the research in learning progressions. This will allow the disjointed nature of astronomy topics in most curricula to be addressed.

We do not imply that learning progressions need to go from local to cosmic nor is it our intention to present a learning progression in this paper. However, it is pertinent to note that there are some conceptual progressions that somewhat warrant this. For example, knowing that we are in a galaxy, there are other galaxies all throughout the universe and that we can use these galaxies to map the evolutionary history of the Universe is a logical sequence that would likely be one, overly simplified just for this example, path in a learning progression. We must emphasize that this paper is not presenting or suggesting a learning progression.

In essence, there needs to be careful consideration of the progression from the immediate astronomical environment, relating to the experience of the sky, to the nonlocal cosmological environment. We propose that the SOLO framework can be used as a guide [49,50] when incorporating astronomy in the curriculum, in order to provide students with a continuity in the progression of content and skills and allow connections to be made across concepts and disciplines [12].

C. Big ideas and curriculum recommendations

The Big Ideas in Astronomy is a document that attempts to capture the core essence of astronomy knowledge for a modern citizen. Students should by the end of schooling have had opportunities to be exposed to, learn, and/or explore the basics of the 11 statements in the Big Ideas. Below, we present the 11 ideas in their logical progression according to the spatial and temporal scales presented earlier:

Immediate astronomical environment (preprimary, primary/elementary) (ages ~6 – 11):

2) Astronomical phenomena can be experienced in our daily lives.

3) The night sky is rich and dynamic.

Local solar environment (middle school) (ages ∼12 − 13):

7) We all live on a small planet within the Solar System.
4) Astronomy is a science that studies celestial objects and phenomena in the Universe.

Local galaxy environment (lower high school) (ages ∼14 − 15):

8) We are all made of stardust.
10) We may not be alone in the universe.

Local extragalactic environment (lower high school) (ages ∼14 − 15):

9) There are hundreds of billions of galaxies in the Universe.

Nonlocal cosmological environment (upper high school) (ages ∼16 − 18):

6) Cosmology is the science of exploring the Universe as a whole.

Cross-content topics (all ages)

1) Astronomy is one of the oldest sciences in human history.
5) Astronomy benefits from and stimulates technology development.
11) We must preserve Earth, our only home in the Universe.

In response to this, we suggest that the following curriculum statements are included in all future curriculum endeavors to bridge the chasm in astronomy school curricula around the world. We present statements that already exist commonly in curricula worldwide, such as the NGSS, ANC, and Swedish curricula above which are broadly representative of astronomy curricula worldwide [4] as well as our suggested statements that need inclusion which we indicate as an * as well as in italics. The new statements are largely drawn from the Big Ideas in Astronomy document [17] while the existing statements are made from an amalgam of the ANC and NGSS statements.

Immediate astronomical environment (pre-primary, primary/elementary) (ages ∼6 − 11):

- identifying celestial objects that can be observed in space such as the Sun, Moon, stars, and planets.
- recording short and longer-term patterns of events that occur on Earth and in the sky, such as the appearance of the Moon and stars at night, the weather, and the seasons.
- Earth's rotation on its axis causes regular changes, including night and day.

Local solar environment (middle school) (ages ∼12 − 13):

- investigating natural phenomena such as lunar and solar eclipses, seasons, and phases of the Moon, comparing times for the rotation of the Earth, the Sun, and the Moon, and comparing the times for the orbits of the Earth and the Moon.
- The orbits of Earth around the Sun and of the Moon around Earth, together with the rotation of Earth about an axis between its North and South poles, cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the Sun, Moon, and stars at different times of the day, month, and year.
- The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them.
- The star called the Sun is changing and will burn out over a lifespan of approximately 10 billion years. The Sun is a star that appears larger and brighter than other stars because it is closer. Stars range greatly in their distance from Earth.

Local galaxy environment (lower high school) (ages ∼14 − 15):

- * Stars and solar systems form from massive clouds of dust and gas (BI 8.2) and go through a stellar lifecycle that ends again with dust and gas (BI 8.6).
- * The human body consists of atoms that can be traced back to earlier stars (BI 8.10).
- * There are numerous planets called exoplanets, which orbit stars other than the Sun (BI 10.5) which can be very diverse and are often found in systems (BU 10.6).

Local extragalactic environment (lower high school) (ages ∼14 − 15):

- A galaxy is a large system of stars, dust, and gas (BI 9.1). There are three main types of galaxies: spiral, elliptical, and irregular (BI 9.4). We live in a spiral galaxy called the Milky Way (BI 9.5).
- * Galaxies can be extremely distant from each other (BI 9.8), form clusters (BI 9.9), and interact with each other through gravity (BI 9.10).

Nonlocal cosmological environment (upper high school) (ages ∼16 − 18):

- identifying the evidence supporting the Big Bang theory, such as Edwin Hubble's observations and the detection of microwave radiation.
- recognizing that the age of the universe can be derived using knowledge of the Big Bang theory.
- describe how the evolution of the universe, including the formation of galaxies and stars, has continued since the Big Bang.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.

The above suggestions may seem that we are on the road of overloading the curriculum, by putting more astronomy in the curriculum. However, we should emphasize that our reasoning is that if the policymakers want to include astronomy in the curriculum, then there should at the very least be a progression and connection between topics.

Furthermore, the curriculum suggestions are based on the curriculum explored in this article, previous research on curriculum by the authors [4], upcoming research [18] on curriculum by the authors, and the Big Ideas endeavor by the IAU [17]. Recent work in review by the authors [15] has shown that out of the over 2000 articles in astronomy education research, only 11 concentrate on galactic and extragalactic topics at any level. There are many more on stars but mostly at the astro101 level. We hope that this paper draws attention to this complex limitation because it is a chicken-and-egg problem! There is little research on these topics at high school because these topics are not in the curriculum. Given that it is not taught, then researchers are not able to explore these topics in the classroom. Without this research, there is little to base a case on its inclusion in the curriculum, leading to a self-perpetuating cycle.

VIII. CONCLUSIONS

Given that astronomy is an area that is of typically high relative interest to students, and its connection within STEM fields and to non-STEM fields, the subject provides a suitable context to leverage its potential to engage students in deeper, connected learning beyond the demarcation of subjects. This paper used examples from the Australian National Curriculum, the USA-based Next Generation Science Standards, and the Swedish National Curriculum. We have shown that topics of astronomy in the curriculum do not follow a natural coherent conceptual progression but that there is a chasm between students who are exposed to seasons, eclipses, planets, and sometimes the Milky Way, in early primary and middle school, but then get launched into cosmology at high school, avoiding numerous important topics in astronomy in between. Comparing this with the Big Ideas document, we see that there is the potential to address this chasm in a way that does not overload the curriculum.

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