Knowing the Universe: Teaching the History and Philosophy of Astronomy

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Abstract

Astronomy is the oldest science, with connections to development of the most important concepts in physics. A course is described that covers its evolution from prehistory to modern cosmology, giving due weight to the philosophical implications of the subject. The pedagogy is designed to let students develop their writing and reasoning skills. The newly developed course has been delivered to three distinct audiences: non-science majors at a major public university, adult community members taking the course for enrichment, and a worldwide audience of lifelong adult learners who enroll in a massive open online course (MOOC). Class content is informed by the scholarly literature on philosophy and the history of physics and astronomy. Subject matter is divided into thirteen chronological topics: Ancient Skies, Greek Science, Revolutions, Telescopes, Gravity, Evolution, Mapping, Relativity, Quantum Theory, Stars and Atoms, Galaxies, the Big Bang, and Life in the Universe. The topics are presented at a rate of one per week during the standard university semester, and they are parsed into five two-hour sessions for the local community audience and seven weeks of self-paced video lectures for the online MOOC audience.

Keywords: Course development; history; philosophy; pedagogy; online

1 Introduction

Astronomy has a history that predates civilizations as humans searched for patterns in nature and used the night sky as a map, a clock, and a calendar (Magli, 2020). Astronomy and philosophy are intimately related, since questions about the nature of the universe and our place within it triggered the development of the scientific method, and the invention of empirical and logical tools for addressing the fundamental nature of both reality and knowledge. Astronomy is also deeply intertwined with physics because the theories of gravity and elementary particles that apply to the universe also operate and are testable in the lab.

The full historical sweep of astronomy, physics and philosophy is covered in a college course called “History and Philosophy of Astronomy.” It was designed as a three-credit, upper division elective class for non-science majors at the University of Arizona and it was taught by the author for the first time in Fall of 2020. The class is small, intended for 15 to 20 students, and it is designed to be delivered either face-to-face or online. Subsequently, the material was converted into a massive open online course (hereafter MOOC), called “Knowing the Universe,” delivered by Coursera and offered for the first time in mid-November 2022. This is the third MOOC that our group has developed, following Coursera offerings on astronomy in 2015 and astrobiology in 2019 (Impey et al., 2016, 2023). The typical audience for most science MOOCs is lifelong learners who are motivated by curiosity and personal interest rather than professional development. In contrast with the typical university class, a MOOC carries no letter grade and no transferrable college credit. The new course was also delivered in the Spring of 2022 to adult learners in the Tucson community, who paid to take it for personal enrichment rather than for college credit.

The history and philosophy of astronomy is a niche subject, so it is not surprising that courses like this are rare. The first version
of the course at the University of Arizona, called “History and Philosophy of Astronomical Thought,” was taught in 1978. At that time, the course number was 120 and it was offered to freshmen as a science elective. In 1993, the course was renamed “History and Philosophy of Astronomy.” It was renumbered to 320, indicating a target audience of upper division undergraduates. For many years, the class was taught solely by Professor Andrzej Pacholczyk of the Department of Astronomy. A web search for “course” or “class” and “history,” “philosophy,” and “astronomy” returns one result: an upper division class called “History and Philosophy of Astronomy” taught at the University of Texas in Austin. This web search, and the others described below, were thorough, but they might not be complete. Most but not all universities make their academic catalogues searchable and have web pages for their individual courses.

Variations on this course are taught at several universities. A web search finds eight courses called the “History of Astronomy,” taught at Cornell, Hawaii, Missouri and Vanderbilt in the United States, York in Canada, London and Sheffield in the United Kingdom, Oulu in Finland, and Bologna in Italy. Four specific courses on the overall history of cosmology or the history of astronomy covering a particular period are taught at Florida in the United States, Alberta in Canada, London in the United Kingdom, and Bologna in Italy. Another web search finds eight courses on the “History and Philosophy of Science.” They are taught at Columbia, Chicago and Pittsburgh in the United States, Cambridge, Leeds and London in the United Kingdom, Utrecht in the Netherlands, and Sydney in Australia. Further searches find three courses on “Physics and Philosophy” in the United Kingdom and one on the “History and Philosophy of Modern Physics” at Indiana in the United States. Many history and philosophy classes are offered as part of undergraduate majors or minors in the United States and the United Kingdom, but they do not concentrate on science, and some are not even specific to science.

The course described in this paper is part of an evolution in the way that science is considered in higher education. Research-intensive universities still train students as the next generation of professional scientists and academics, although the narrowness of that goal is questioned given the wide range of career paths for students trained in science (Kwok, 2018). The broader remit of universities is to train all students in scientific ways of thinking that will make them better citizens. This was the motivation for general science courses that proliferated in the United States (Heffron, 1995). It is also the motivation for using history and philosophy to show the profound ways science has shaped our understanding of the natural world and our place in it. A convincing case has been made for including history and philosophy in science education (Matthews, 2021) and others have argued for the importance of history and philosophy to astronomy (Gingerich, 2018; Dick and Dick, 2020). It is noted that tension between the fields has led some physicists to eschew philosophy (Rovelli, 2018a). This paper adds to the very limited literature on the use of history and philosophy to teach astronomy (Tignanelli and Benetreau-Dupin, 2013).

2 Development of the Course

2.1 Undergraduate College Class

Astronomy 320, History and Philosophy of Astronomy, is offered once per year by the Department of Astronomy at the University of Arizona. It has no prerequisites and is taken by mostly juniors and seniors. Students in the class have a wide variety of majors. Most are in the Liberal Arts while some are STEM majors or students taking a minor in astronomy (it does not satisfy a requirement for the astronomy major). Half a dozen different instructors have taught the course over the years, and each gives it their own emphasis. Some stress connections to philosophy and epistemology, while others only cover a partial history of the subject, such as from the ancient Greeks to Newton or just the previous century. The version of the course described here is highly interdisciplinary. It was originally offered online only in 2020 during the early phase of the pandemic, and for the second time in 2021 in hybrid mode, both online and face-to-face. It was taught in 2023 as a face-to-face class. The enrolment is typically a dozen students, and the attrition rate is negligible.

The ethos of the class is encapsulated in the famous woodcut shown in Figure 1.

2.2 Massive Open Online Class

Development of a massive open online version of the class began in early 2021. The core of the MOOC is the same set of video lectures used for the University of Arizona class during the pandemic. Coursera was chosen as the provider since they partner with universities and the author has ten years of experience working with them. The Coursera platform hosts and delivers content, provides tools for building quizzes and conducting peer-reviewed writing assignments, and hosts discussion forums and ways for learners to give feedback and evaluate the course. They also provide analytics to measure learner demographics and track engagement, like the number of videos watched and assessments completed. The author has extensive experience with the Coursera platform, with over 280,000 learners enrolled in three other courses. Learning is asynchronous and people enrol anytime, and the class is designed to be taken over seven weeks, since that interval best matches the needs of adult learners who often have jobs and family responsibilities. The new, free MOOC, which is titled “Knowing the Universe: History and Philosophy of Astronomy,” was launched in November 2022 (Coursera, 2022). The graphic for the course is shown in Figure 2.

2.3 Humanities Seminar Program

The Humanities Seminar Program of the College of Humanities at the University of Arizona is an outreach initiative designed to let members of the Tucson community experience the best instruction the university can offer. It has been running since 1988 and offers 25 to 30 courses every year, mostly in the Arts
and Humanities. The courses range from 8 to 30 hours in length and span 4 to 10 weeks. The author has prior experience with the program, having taught a class called ’Enigmas of the Universe’ to 264 students in 2019. ’Knowing the Universe’ was taken by 63 adult learners in the Spring of 2022, with a mixture of virtual and face-to-face participants (Humanities Seminar Program, 2022). Live lectures were the primary mode of instruction, and PowerPoint slides were made available as pdf files along with videos of the lectures. Participants paid a fee to take the class, but no grades were given and no quizzes or homeworks were required. Classes were given in two-hour blocks which included 30 minutes for questions and answers and general discussion. A still from the lecture video covering the ancient Greeks is shown in Figure 3.

3 Pedagogy of the Course

3.1 Video Lectures

The core element of all three versions of ’Knowing the Universe’ is a set of video lectures. For the three-credit University of Arizona class, they are used to review the material or to catch up when a student misses a class. For the Humanities Seminar, they are used for asynchronous learning by virtual participants. For the MOOC, they are the only means of accessing the lecture material. The total content of the course is 85 individual topics adding up to 18 hours of lecture video. The videos for the individual topics ranged from 6 to 21 minutes in length, with an average of 13 minutes. The optimum length for an instructional video is debated, with cognitive load as the concern for longer videos (Brame, 2015). Evidence from one study pointed to an optimum length of 6 to 10 minutes (Manasrah et al., 2021), while a larger study of educational videos on YouTube found that anywhere from 5 to 20 minutes long could yield the most engagement and the best watch time percentage (Likness, 2021). New video platforms like TikTok tend to prefer short videos, but the YouTube recommendation algorithm has been giving preference in searches to longer videos since 2012 (Peterson, 2018).

Good quality educational videos can be made without using a professional studio and a green screen. The course videos were shot with a Canon EOS 80D digital camera and a lavaliere microphone. Video was captured using the free, open source OBS streaming app running on a Windows desktop computer (Software, 2022). HD resolution of 1280 x 720 pixels was used. The video editing was done in Adobe Premiere. For visual variety, the presentation toggled between four OBS templates, where the location and size of the “talking head” varied with respect to the PowerPoint slides, which were captured as the second video input. Short video clips and animations were interspersed between the slides, occupying the full real estate of the screen. In the undergraduate class, the content spanned the 13 weeks of a semester, with one module per week typically covering 6 topics and 80 minutes of video lecture. For the Humanities Seminar Program and the MOOC, content was repackaged into 5 weeks and 7 weeks, respectively. Video watching patterns in a MOOC differ from a college class as only a small fraction of learners will complete the course. Early videos have much higher viewing statistics than videos near the end of the course (Impey et al., 2015).

3.2 Content

’Knowing the Universe’ is a course that requires no background or prior experience in astronomy. Science and philosophy terms are explained as needed. There is no required textbook. As enrichment material, a set of YouTube videos was curated and made available to students, with credit awarded for watching a significant number of them. There were 8 to 10 videos per
week or module, totalling 40 to 60 minutes of watch time. The course content is non-mathematical, but it is pitched at a high conceptual level. Brief summaries of the major themes of each module follow.

3.2.1 Ancient Skies
Astronomy is the oldest science because it has had practical importance for people all over the world since the dawn of civilization. The night sky was a map, a clock, a calendar, and a book of stories. Monuments like Stonehenge and Chichen Itza encapsulated both astronomy and cultural knowledge (Polcaro and Polcaro, 2009). There is bias towards the Western tradition so the uses of astronomy by cultures in Africa, Asia, and South America are still being discovered (Figure 4). The earliest calendars were based on the cycle of Moon phases (Richards, 2000), and timekeeping in the modern world combines practices first developed thousands of years ago in Babylonia, Egypt, Greece, and Rome.

3.2.2 Greek Science
Ancient Greek philosophers enabled new ways of thinking about nature and the cosmos with their invention of logic and mathematics. Although they did not make advances in experimental science, their use of thought experiments was innovative and continues to be a part of physics. They were the first to make mental models of natural phenomena. Using these methods, Greek philosophers estimated the Earth’s size, they inferred the existence of atoms, and they speculated that Earth was not at the center of the universe (Pedersen, 1974). Their cosmology possessed an aesthetic aspect, with the idea of the warring opposites of cosmos, or order, and chaos, or disorder.

3.2.3 Revolutions
The Renaissance was incubated in Islamic countries in the 11th and 12th centuries, where important advances in optics were made. Copernicus lit a slow fuse on a revolution that impacted the whole European culture, as displacing the Earth from the center of the universe threatened the cozy Christian pact between Man and God (Figure 5). The heliocentric model violated a core precept of the scientific method by not fitting planetary orbits better than the geocentric model but it had the benefit of giving a natural explanation for the retrograde motion of Mars (Kuhn, 1992). The Copernican Revolution led to the birth of recognizably modern science in the hands of Galileo Galilei. There is a through line of Copernican thinking that extends to the present, with displacement of the Earth to a position of cosmic insignificance in a universe overwhelmingly composed of dark matter and dark energy, and perhaps, a universe where biology is not limited to the Earth (Figure 6).

3.2.4 Telescopes
Greek philosophers established two lines of scientific inquiry. One was epitomized by Plato, who imagined that nature could be understood by the application of pure thought. The other was epitomized by Aristotle, who believed in observation, but rooted in common sense and intuition. Modern science adheres to Aristotle but gives primacy to experiments and physics underpinned by mathematics. Galileo operated in a way that would be recognizable to a modern scientist, extending to his publishing his data for a broad audience. He used the newly invented telescope to debunk Aristotelean physics and show that the Earth was one of “many worlds” (Livio, 2020). Modern telescopes have millions of times the light-gathering power of Galileo’s best instrument (Watson, 2007).

3.2.5 Gravity
Science was a major beneficiary of the Enlightenment, the flow of ideas throughout 17th century Europe that emphasized individualism and reason over tradition. Isaac Newton sits firmly in that tradition in England, where science propagated informally in clubs and tea or coffee houses, and the first scientific society was formed. His contributions were massive, from theories of optics, mechanics, and gravity to the invention of the calculus. Newtonian gravity became part of a “clockwork universe” metaphor, and the idea of a completely predictable universe generated a backlash from humanists (Dolnick, 2011). The physics innovations of Newton enabled the inventions that propelled the Industrial Revolution in Britain.
3.2.6 Evolution

Cyclic time was embraced by prehistoric cultures across the world as they synchronized their lives to motions of the heavens. However, this was at odds with human experience and an arrow of time where the past could not be revisited. The idea of “deep time” emerged in the 18th century in England, as the geologist James Hutton observed the strata of the Earth and deduced that slow, inexorable changes could accumulate to dramatic effect over many millions of years. A century later, biology was connected to this timeline through Darwin’s insight into natural selection. The fossil record was a representation of the deep time of biology in geology. Earth has evolved for over four billion years, and over that span, starting with a single common ancestor, life has proliferated over the planet, occupying a dizzying range of ecological niches (Ruse and Travis, 2018).

3.2.7 Mapping

Science advanced during the Enlightenment on all fronts, and the growth of universities in Europe and the United States in the 19th century fuelled science as a profession. Mapping was the method used to improve our knowledge of the Earth and the cosmos. On the Earth, any position can be defined by two angles: latitude and longitude. Latitude is measured with stars, but on the spinning Earth, measuring longitude depends on timekeeping (Sobel, 2007). On the sky, positions are also measured by two angles, but those angles give no information about the distance to astronomical objects or their physical properties. Solving the longitude problem by better timekeeping allowed astronomers to measure the scale of the Solar System and the distances to stars for the first time. Mapping the universe in three dimensions continues to be the goal of astronomy.

3.2.8 Relativity

There was a sense that theories of physics were complete by the end of the 19th century, but a revolution was brewing (Figure 7). Experiments had failed to detect ether, a hypothesized invisible medium that could define absolute motion and through which light was supposed to travel. The constancy of the speed of light led Albert Einstein to a special theory of relativity (Morin, 2017). The radical implications of the theory are that time slows down, and objects shrink and become more massive as they approach the speed of light. Mass is a form of “frozen” energy. Einstein’s general theory of relativity is equally radical, and it replaced the linear, absolute space and time of Isaac Newton with hyphenated space-time, which is curved by mass-energy (Iaacson, 2007). The theory was quickly tested during a 1919 solar eclipse, and it has since been confirmed by lab measurements and astronomical observations over the past century.

3.2.9 Quantum Theory

Quantum theory is an invisible substrate of the modern world. Electronics, lasers, and medical imaging technologies like MRI are based on it. When the theory was developed in the early 20th century, it upended intuition about how the natural world works. The microscopic world is granular and discrete not smooth and continuous. Waves act like particles and vice versa. There is a fundamental limit to the precision with which anything can be measured in the physical world, set by Heisenberg’s uncertainty principle (Rovelli, 2018b). Quantum theory raises profound philosophical questions, most of which are not resolved. Yet it is a highly successful theory that explains everything from the inner working of stars to the methods by which the next generation of computers will be designed.

3.2.10 Stars and Atoms

As far as we know, the laws of physics are universal and apply equally in the lab on Earth and within distant stars. Using the new quantum theory, astronomers figured out how the Sun and all other stars produce energy with the process of nuclear fusion (Chown, 2000). More massive stars can generate higher core temperatures and they ascend the chain of fusion to create elements as heavy as iron. Most of the heaviest elements require stellar cataclysms. Stars are chemical factories and the periodic table is a testament to stellar astrophysics. At the end of a star’s life, gravity is the victor, and the end states of stars are a bizarre set of highly condensed forms of matter: white dwarfs, neutron stars, and black holes.

3.2.11 Galaxies

Through the 19th century astronomers had mapped our position in a vast assemblage of stars called the Milky Way. But in the 20th century, Edwin Hubble redefined our relationship to the universe with two discoveries. First, he showed that Andromeda and other spiral nebulae were distant systems of stars, or “island universes” (Eicher, 2020). To do this he had to assume that the laws of physics operate in remote regions of space as they do on the Earth. More recent surveys have mapped out a large-scale structure of galaxies in groups and clusters, with immense voids between them. Second, he found that the light of galaxies was redshifted, and the more distant the galaxy, the larger the redshift. This is interpreted as the expansion of the universe. Modern astronomers learned that all the stars in the hundreds of billions of galaxies in the universe have a total mass that is dwarfed by two enigmatic ingredients of the universe: dark matter and dark energy (Panek, 2011).

3.2.12 Big Bang

Rewind the “clock” on the expanding universe and it implies a time in the distant past when the universe was far smaller, denser, and hotter than it is now. This origination event is the big bang. Astronomers use telescopes as time machines; since remote light is old light, by looking out in space they can look back in time. By the end of the 20th century, evidence that the big bang occurred had become compelling (Singh, 2005). The initial, hot dense phase explains the abundance of light elements in the universe, and it is the cause of a sea of leftover radiation that is detectable in every direction as low energy microwaves. There is evidence for an exponential expansion very early on, which implies the universe began as a quantum event (Figure 8). Various ways of seeing the universe in invisible forms of radiation have been essential in developing this understanding.

3.2.13 Life in the Universe

It would be a continuation of the Copernican Revolution if we were able to show that the Earth is not the only living world (Figure 6). Life beyond the Earth has not yet been found, but astronomers are confident it exists. The chemical ingredients

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Figure 7. A frame from the animated trailer for the MOOC, “Knowing the Universe,” showing images that represent the revolution in physics in the early 20th century and progress in cosmology throughout the 20th century (Credit: Chris Impey and the University of Arizona).
As mentioned earlier, MOOCs appeal to a worldwide audience. There are billions of Earth-like and potentially habitable planets, offering a vast number of potential locations for life to evolve. The search for life takes three routes, with the most probable locations being the habitable zones of stars. The probability of finding life on exoplanets is heavily represented than for MOOCs in general. Europe, and English-speaking countries like Canada, the U.K., and Australia are more heavily represented than the average. The demographics of learners in an astronomy MOOC compared to all other subjects offered by Coursera. Three quarters are not full-time students, 36% are employed, 23% are unemployed, and 18% are retired. In terms of education, 31% have a bachelor’s degree, and 40% have an advanced or professional degree. In the Humanities Seminar, a minority of learners are taking the course to fulfill a requirement in the General Education program, with far fewer motivated by grades or any tangible outcome. Figure 11 below lists the responses of the MOOC learners.

The MOOC learners and college students were also asked, using different instruments, why they signed up for the class. They could select as many reasons as they wanted. Figure 12 below lists the percentage of learners in each situation showing that they are self-motivated and not aiming for a grade or any long-term commitment to science. Career motivation is weak since they are non-science majors with no long-term commitment to science. The MOOC learners in Figure 9. The top panel shows that the astronomy MOOC has a larger proportion of people at or above retirement age and a lower proportion of people thirty years younger. The students are two-thirds male and one-third female, a slightly higher proportion of men than for MOOCs in general. As of May 2023, just over 2200 people had enrolled in the first six months of the course. From data in the bottom panel of Figure 9, about 60% are based in the United States, a higher proportion than MOOCs in general. Europe, and English-speaking countries like Canada, the U.K., and Australia are more heavily represented than the average. Figure 10 shows employment status and highest level of education for the astronomy MOOC, compared to all other subjects offered by Coursera. Three quarters are not full-time students, 36% are employed, 23% are unemployed, and 18% are retired. In terms of education, 31% have a bachelor’s degree, and 40% have an advanced or professional degree. Compared to typical Coursera learners, the astronomy MOOC participants are more likely to be retired and highly educated.

Figure 8. Ways of Seeing the Universe. After millennia of observations with the naked eye, the telescope expanded our light grasp by factors of millions. In the 20th century, the electromagnetic spectrum was opened for astronomical observation, and recently, gravity waves allow us to “see” mass directly (Credit: Chris Impey and the University of Arizona).

3.3 Demographics

As mentioned earlier, MOOCs appeal to a worldwide audience of adult, lifelong learners. The demographics of learners in the Coursera “Knowing the Universe” MOOC are compared with all Coursera MOOCs in Figure 9. The top panel shows that the astronomy MOOC has a larger proportion of people at or above retirement age and a lower proportion of people thirty years younger. The students are two-thirds male and one-third female, a slightly higher proportion of men than for MOOCs in general. As of May 2023, just over 2200 people had enrolled in the first six months of the course. From data in the bottom panel of Figure 9, about 60% are based in the United States, a higher proportion than MOOCs in general. Europe, and English-speaking countries like Canada, the U.K., and Australia are more heavily represented than the average. Figure 10 shows employment status and highest level of education for the astronomy MOOC, compared to all other subjects offered by Coursera. Three quarters are not full-time students, 36% are employed, 23% are unemployed, and 18% are retired. In terms of education, 31% have a bachelor’s degree, and 40% have an advanced or professional degree. Compared to typical Coursera learners, the astronomy MOOC participants are more likely to be retired and highly educated.

The demographics of the Humanities Seminar offering of the class [not shown in this paper] skewed even older than the MOOC, since that program mainly attracts retired members of the Tucson community. A minority of Humanities Seminar learners are male (40%), as opposed to two-thirds for the MOOC. As with the MOOC learners, a majority have advanced or professional degrees. By contrast, the undergraduate college class is typical of any large public university. Among 44 students in the first three offerings of class, there have been 55% men and 45% women, and 90% were juniors and seniors, so in a narrow age range of 20 to 22 years old. They span a range of academic interests, with 50% majoring in science and engineering, 30% majoring in social science, arts, and humanities, and 20% in the professional schools of business, law, and medicine.

3.4 Motivations

Our group has done research on the different motivations of learners in an astronomy MOOC and the relationship of motivation to engagement in the course (Formanek et al., 2019). No data exists on the motivations of adults in the Humanities Seminar. Most relevant to this paper is potential differences in motivation between informal MOOC learners and the more formal college students. A direct comparison is not possible, but proxies exist by using the astronomy MOOC already studied and the non-science majors in an introductory astronomy class at the University of Arizona taught by the author. The demographics of the astronomy MOOC are almost identical to the demographics of the “History and Philosophy of Astronomy” MOOC, and the student population in all types of astronomy class for non-majors is similar. If these proxies are accepted, there are some striking differences in the motivations of the different audiences.

Both groups were administered the science motivational questionnaire developed by Glynn et al. (2011). This instrument has been extensively tested and validated. Students rate 35 statements distributed among 7 motivational categories, then a factor analysis assigns them each a strength on a scale of 1 to 5. Figure 12 below lists the percentage of learners in each situation showing that they are self-motivated and not aiming for a grade or any tangible outcome. Figure 11 below lists the responses of the college students. The great majority are taking the class to fulfill a requirement in the General Education program, with far fewer motivated by curiosity or an interest in astronomy. Almost none of the students consider astronomy relevant to their future career. To summarize, the students in the informal setting have much less interest in the subject matter than students in the formal setting.

4 Evaluations

Having discussed the varying reasons why these three populations of learners took the course, information is presented on how well it suited their needs. The MOOC had the least amount of feedback, since Coursera only provides a mechanism to “like” or “dislike” the course and rate it on a scale of one to five stars. As of May 2023, “Knowing the Universe” had 199 likes (98%) and 4 dislikes (2%). There have been a modest number of 9 reviews, with an average of 4.9/5 stars, compared to an average for all
Coursera offerings of 4.7/5 stars. It is concluded that the MOOC meets the needs of these lifelong learners. For the Humanity Seminar version of the course, participants answered an online questionnaire. The number of responses was 62, from an initial enrolment of 102 which dropped to an average attendance of 67. Therefore, the response rate among those who routinely attended the class was 93%. The results are illustrated in the next two figures. Figure 14 shows the responses to three questions about the subject matter and the value for money of the course. Figure 15 shows responses to six questions about the instructor. These evaluations demonstrate a high degree of satisfaction with the course and instructor.

For the university course, evaluation is a more rigorous procedure, since the results are considered in faculty performance evaluation, and for pay raises. Students evaluate the class anonymously using a secure website and the results are reported to the instructor and their department after grades have been finalized. With this small enrolment class, results from the first two offerings on the class in 2020 and 2021 are combined. The response rate was 18/22 or 82%. A total of 54 comments were received, almost all positive. Figure 16 gives results for the first six questions from the survey instrument. For all six questions, over 90% of the feedback was positive, often strongly positive. Despite the fact that the course did not directly advance the
career goals of the non-science majors who took it (and it was not in fact designed to), it did provide tangible educational value. While astronomy is an esoteric subject, the students affirmed that the knowledge and concepts learned could be applied to the real world.

### 4.1 Engagement

Of the three versions of the class, the Humanities Seminar gave the least opportunity to measure engagement. Attendance was high and steady throughout the semester, but apart from questions during the after the lectures, participants were not asked to take quizzes and do assignments. The Coursera MOOC included 42 short quizzes, which were built into the lecture videos. At particular points, the videos would pause, and learners were asked to answer several multiple-choice questions before continuing the video. They could easily decline and watch the videos uninterrupted. MOOCs attract people who are interested in a topic but who have many demands on their time and often have jobs and families. Therefore, the attrition rate is high (Goopio and Cheung, 2021). In our first astronomy MOOC, launched

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**Figure 11.** The strongest motivational factors for the astronomy students in a Coursera MOOC and an undergraduate college class at the University of Arizona, based on a factor analysis of a 35-item instrument developed by Glynn et al. (2011)

<table>
<thead>
<tr>
<th>Metric</th>
<th>High</th>
<th>Coursera learners</th>
<th>College students</th>
</tr>
</thead>
<tbody>
<tr>
<td>self determination</td>
<td>38.2%</td>
<td>32.3%</td>
<td>22.1%</td>
</tr>
<tr>
<td>career</td>
<td>35.4%</td>
<td>35.4%</td>
<td>21.1%</td>
</tr>
<tr>
<td>grade</td>
<td>31.6%</td>
<td>64.1%</td>
<td>64.1%</td>
</tr>
<tr>
<td>astronomy hobby</td>
<td>80.9%</td>
<td>38.1%</td>
<td>17.6%</td>
</tr>
<tr>
<td>social</td>
<td>9.1%</td>
<td>17.6%</td>
<td>17.6%</td>
</tr>
<tr>
<td>intrinsic</td>
<td>83.2%</td>
<td>41.7%</td>
<td>41.7%</td>
</tr>
<tr>
<td>self efficacy</td>
<td>59.1%</td>
<td>42.3%</td>
<td>42.3%</td>
</tr>
</tbody>
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**Figure 12.** Stated reasons for taking the online astronomy course by Coursera learners in the fall of 2017. The demographics of this course closely match the "History and Philosophy of Astronomy" MOOC that is discussed in this paper.

<table>
<thead>
<tr>
<th>Reason</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>It fulfills a Gen Ed requirement</td>
<td>546</td>
<td>85.6%</td>
</tr>
<tr>
<td>I have an interest in astronomy</td>
<td>371</td>
<td>58.2%</td>
</tr>
<tr>
<td>It fits my schedule</td>
<td>301</td>
<td>47.2%</td>
</tr>
<tr>
<td>because it satisfies my curiosity</td>
<td>277</td>
<td>43.4%</td>
</tr>
<tr>
<td>Thinking about becoming an astronomy major or minor</td>
<td>56</td>
<td>8.8%</td>
</tr>
<tr>
<td>Reputation of the instructor</td>
<td>55</td>
<td>8.6%</td>
</tr>
<tr>
<td>Recommendation from a friend or colleague</td>
<td>48</td>
<td>7.5%</td>
</tr>
<tr>
<td>to interact with other people taking this class</td>
<td>28</td>
<td>4.4%</td>
</tr>
<tr>
<td>it is relevant to my future career</td>
<td>23</td>
<td>3.6%</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>15</td>
<td>2.4%</td>
</tr>
</tbody>
</table>

**Figure 13.** Stated reasons for taking and introductory astronomy course by college students in the fall of 2017. The demographics of this course closely match the Astronomy 320 class discussed in this paper.

<table>
<thead>
<tr>
<th>Reason</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>It fulfills a Gen Ed requirement</td>
<td>546</td>
<td>85.6%</td>
</tr>
<tr>
<td>I have an interest in astronomy</td>
<td>371</td>
<td>58.2%</td>
</tr>
<tr>
<td>It fits my schedule</td>
<td>301</td>
<td>47.2%</td>
</tr>
<tr>
<td>because it satisfies my curiosity</td>
<td>277</td>
<td>43.4%</td>
</tr>
<tr>
<td>Thinking about becoming an astronomy major or minor</td>
<td>56</td>
<td>8.8%</td>
</tr>
<tr>
<td>Reputation of the instructor</td>
<td>55</td>
<td>8.6%</td>
</tr>
<tr>
<td>Recommendation from a friend or colleague</td>
<td>48</td>
<td>7.5%</td>
</tr>
<tr>
<td>to interact with other people taking this class</td>
<td>28</td>
<td>4.4%</td>
</tr>
<tr>
<td>it is relevant to my future career</td>
<td>23</td>
<td>3.6%</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>15</td>
<td>2.4%</td>
</tr>
</tbody>
</table>
with Coursera in 2015, half of the people who enrolled did not complete the first assignment, and there was a sharp drop-off in participation in the first week of the class (Impey et al., 2016). Figure 17 shows a similar pattern for the quizzes in the “History and Philosophy of Astronomy” MOOC. Only 22% of nearly 2200 enrolled learners completed the first quiz, and there is a further decline in participation by a factor of nearly 4 over the next two weeks, after which participation is stable.

A college class does not suffer the same attrition rate as a MOOC, since students are often fulfilling a requirement or need the class to graduate. In the ASTR 320 class, much of the engagement came from discussion that occupied half the time in the classroom, as discussed later. A good vehicle for asynchronous engagement was VoiceThread, a tool that lets students build and share presentations (Erickson, 2020). As a small part of their overall grade, students were asked to comment on the weekly VoiceThread homework assignments of other students. Figure 18 shows an example. Making dozens of these comments over the semester not only helped students engage with each other, it also helped them learn the skill of giving constructive feedback. Engagement can be induced by modest levels of reward. Students had 5% of their grade for making an average of five VoiceThread comments per week, and another 5% for watching an average of five videos per week. As Figure 19 illustrates, many students did more than 65 of each over the 13-week semester, even though that extra effort would not benefit their grade. The weak correlation of participation in these two activities with total class score is evidence that they were motivated by engagement rather than grades.
4.2 Assessments

The type of assessments used in the course depend on the audience. A college audience is getting a letter grade or pass/fail grade and the three credits are part of an undergraduate degree program requiring at least 120 credits. Assessments need to be keyed to learning goals, so students know what to pay attention to in a class where they will be presented with a large amount of material. Learning goals for the history and philosophy of astronomy class are that students should be able to: (1) appreciate the role of logic and science method in advancing astronomy knowledge, (2) understand how different cultures conceived of space and time through history, (3) describe how dramatically our concept of the universe has changed in the past century, (4) convey aspects of astronomy in a way that any non-science major would understand, (5) recognize the different roles of theory and observation in advancing our knowledge, (6) describe the relationship of astronomy to other fields of science, and to religion, (7) see how science strives for objectivity, but also operates as a human, cultural activity, (8) understand how philosophical thinking can advance astronomical knowledge, and (9) demonstrate comprehension of a topic by creating a multimedia presentation.

The grade breakdown for the college class is 60% for weekly homework assignments, one for each module, 20% for a semester-long multimedia project, and 20% for class participation and engagement. The homework is done in VoiceThread (Erickson, 2020), a collaboration and sharing tool that lets stu-
students build online presentations by combining images, videos, documents, audio files, and other media to which other students can add comments to generate discussion. Every week, students can select from one of six prompts. As an asynchronous learning tool, VoiceThread proved extremely useful during the pandemic when classes were online (Burgner, 2019). But it is equally valuable in a face-to-face class, where it has been shown to foster student engagement and collaboration (Saçak and Kavun, 2023). VoiceThread is fully integrated into D2L, the learning management system used by the University of Arizona and 12% of colleges nationwide (Francom et al., 2021). The semester-long project is a more detailed, well-researched version of the weekly assignment, counting for a larger portion of the grade and also presented in VoiceThread. The final part of the grade rewards participation, based on a combination of classroom attendance, watching lecture videos and related YouTube videos, and making comments on other students’ weekly VoiceThread assignments.

In contrast to the college class, the informal learners in the Humanities Seminar version of the course have no assessments at all. The MOOC learners are also under no obligation to do anything other than watch the video lectures. The course is free, and this is the route taken by most learners, called auditing by Coursera. People can also choose to pay for a completion certificate. However, the self-motivated adult learners that are typical in MOOCs often take the assessments even if they are not aiming for a completion certificate (Formanek et al., 2019; Semenova, 2022). In the “Knowing the Universe” MOOC, there are seven weekly quizzes of the content, each counting 6% and totalling 42% of the grade, and seven short writing assignments totalling 41% of the grade. The final 2% is for completing a survey at the start of the course. With large number of students, manual grading of writing is not feasible, so Coursera’s peer-writing evaluation tool is used (Formanek et al., 2017). Those who score over 50% on the assessments graduate and those who score over 80% graduate with distinction.

4.3 Classroom Discussion

Most college classes still rely heavily on lectures, even though engaging students with active learning produces better outcomes (Faust and Paulson, 1998). In this history and philosophy class, only one of the two weekly time slots is used for lecturing, with ample time for questions during and after the lecture. The other class time slot is used entirely for discussion, with students working in pairs. Each week, six prompts are presented, and students select which one they want to discuss. They are already familiar with the material because they will have seen it in a preceding lecture. Each pair presents the results of their dialog to the class, then there is general discussion. The same six prompts are used for that week’s homework, so students have been well-primed to think deeply about the issues by the time they do the homework.

As examples of these prompts, these are the six used in the first module on “Ancient Skies”: (1) What was the practical importance of astronomy for humans living a nomadic life in Africa tens of thousands of years ago? (2) How large do you think people thought the Earth or the universe was before the epoch of human civilization, and why? (3) If you were living within a tribe of hunter-gatherers thousands of years ago, how would modern knowledge of physics and astronomy be useful? (4) Assuming you spoke the same language, but had no modern or technical terms, how would you describe the universe to a cave person? (5) If you lived in ancient Egypt or Mesopotamia, how might you use detailed knowledge of eclipses and transient sky phenomena to gain status or get rich? (6) Invent a new, original creation myth about the creation of the world, the universe, and humans.

Another strategy to encourage discussion in the class is the use of rhetorical devices. Hypothetical situations are imagined or suggested and not necessarily real or true. Counterfactuals state something that might be true, or something that isn’t true but might have been true. They involve causal reasoning since a counterfactual involves mentally traveling back in time to imagine a change to what actually happened, then imagining how that alternative possibility would have played out, while a hypo-
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Figure 19. Total class score versus number of VoiceThread comments (top) and number of videos watched (bottom), from ASTR 320 taught in 2023. In each case, maximum credit is earned by making five comments per week or watching five videos per week, so any total over 65 does not benefit the grade, yet many students do more than is needed.

Theoretical imagines a possible change in the future (Gerstenberg, 2022). These methods are introduced early in the course since, in the absence of experimentation, the ancient Greeks used them extensively (Wohl, 2014). Some examples from the dozens used in throughout course are: (1) Was civilization inevitable, and would science have been possible without it? (2) What if the telescope had been invented at the time lenses were first perfected, in the 14th century? (3) How would the natural world be different if events did not have apparent causes? (4) Is there any objective reality that is independent of observations? (5) What would the universe be like if stars had not created elements? (6) How could we tell if we were living in a simulation?

4.4 Lessons Learned

Some of the lessons learned in the creation and teaching of the history and philosophy of astronomy course at the University of Arizona would sound familiar to anyone teaching at a large public university. Students need modest incentives in the grading scheme to regularly come to class and participate in discussions. They benefit from continuous assessment during a long semester. They need guidance on going beyond secondary sources like Wikipedia when they give references for written assignments. Peer learning helps in any college class. In this class, pairwise discussion helped trigger broader discussion in the entire class. Students having to comment on each other’s VoiceThread assignments improved the quality of those assignments over the semester. The tendency to think there is a “right” answer hindered their ability to think outside the box when open-ended questions were posed in class. Overall, student evaluations of the course were excellent. In the first two cohorts of students, 83% strongly agreed that “this course expanded my knowledge and skills in this subject matter” and 89% strongly agreed that “this course helped me connect the concepts and skills we learned to the world around me.”

A useful lesson learned in the creation of videos for the MOOC is that it’s not essential to use a professional studio to create high quality, visually interesting video lectures. Reasonably priced hardware and open-source software suffice. The Coursera peer review mechanism worked well but it should be set to penalize tardy participation. Also, writing assignments had to be kept short (300 to 500 words), and a relatively coarse rubric worked best (5-point scale). It is advisable to use the Coursera mentor program to help monitor the discussion threads in a course with hundreds or thousands of participants. Mentors are people who have completed the course and are motivated to help others learn. They answer most simple questions and only involve the
instructor with difficult questions or if a discussion thread gets contentious. To give MOOC learners direct access to the instructor, live Q&A sessions are offered on YouTube every couple of weeks. Coursera has excellent bandwidth for video streaming so there are rarely complaints about the MOOC platform. For university faculty, a MOOC is an excellent form of outreach.

5 Acknowledgements

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6 Declarations

6.1 Ethical Approval

This study was conducted with approval from University of Arizona IRB under protocol number 1611014283.

6.2 Consent for Publication

Not applicable.

6.3 Competing Interests

Not applicable.

6.4 Funding

Not applicable.

References

Simon & Schuster.