Study Of Faculty Instructors In Undergraduate Classroom And Planetarium Learning Environments

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ABSTRACT

A mixed-methods study exploring the undergraduate planetarium learning environment was conducted during the 2019--2020 academic year at a western American university. Survey responses from university faculty, observational data using the Classroom Observation Protocol for Undergraduate STEM (COPUS), and faculty interview responses were collected and analyzed to investigate how and why collegiate undergraduates were being instructed in a planetarium environment and how this environment compared to a traditional classroom counterpart. Results suggest that planetarium use is viewed by instructors as an integrated learning experience with the classroom environment, with affective learning outcomes in the planetarium complemented by cognitive learning outcomes in the classroom. COPUS observations of planetarium instruction show broad similarity to classroom instruction; however, reductions in active-learning behavior archetypes measured in the planetarium environment suggest a trade-off between interactive learning strategies and visually immersive content presentation. Implications concerning the collegiate planetarium environment and future work are discussed.

Keywords: Discipline-Based Astronomy Education Research; Planetarium Learning Environment; Undergraduate Education; COPUS

INTRODUCTION

The use of the planetarium setting has long been associated with astronomy instruction as a place to enhance learners' experience with astronomical content. Given astronomy's historical record as a difficult discipline to both instruct and learn, the planetarium environment is seen as providing a unique and immersive visual experience that aids learners in constructing and cementing the understandings necessary for astronomical comprehension (Brazell & Espinoza, 2009; Slater & Tatge, 2017). The progressive increase of immersive projections in a digital fulldome planetarium has offered greater opportunities for visitors to learn in a three-dimensional (3D) simulated environment (Wyatt, 2005; Yu, 2005). Such environments can help learners of any age by providing different spatial perspectives and fully rendered 3D simulations of concepts that can relieve learners of cognitive load and enhance learning (Sumners, Reiff, & Weber, 2008; Carsten-Conner, Larson, Arseneau, & Herrick, 2015; Türk & Kalkan, 2015; Chastenay, 2016). For collegiate learners specifically, those who experienced lessons in the planetarium have been shown to not only achieve greater learning gains than their classroom-only contemporaries but also to better retain those gains over time (Zimmerman, Spillane, Reiff, & Sumners, 2014; Yu, Sahami, Sahami, & Sessions, 2015; Yu, Sahami, Denn, & Sahami, Sessions, 2016; Yu, Sahami, & Dove, 2017).

Collegiate learners are a group of particular educational interest—these learners have been notorious for maintaining particularly entrenched misconceptions of basic astronomy concepts which must be undone if meaningful instruction is to occur (DeLaughter, Stein, Stein, & Bain, 1998; Zeilik, Schau, & Mattern, 1998; Trumper, 2000; Prather, Slater, & Offerdahl, 2003; Miller & Brewer, 2010). Collegiate instruction in astronomy has undergone a metamorphosis in recent years (Waller & Slater, 2011). Education research efforts in physics and astronomy have previously highlighted a shortcoming with classical instructional techniques in the lecture hall setting: they were not particularly effective towards achieving the desired learning outcomes. These ineffectual strategies were far too "instructor-centered," relying upon old—and sometimes ancient—suppositions about the learning process where an instructor filled their otherwise knowledge-devoid learners with information and the learners would then internally synthesize this information into a perfectly accurate knowledge base (Slater, 2003). Needless to say, that supposition was inaccurate, infamously illustrated by Schnep's interviews of Harvard graduates' astronomical misconceptions in A Private Universe, where recent graduates were incapable of providing scientifically accurate explanations for basic astronomical phenomena (Schneps, 1989; Bailey & Slater, 2004).

The philosophical foundation here is that students do not enter classrooms as empty vessels, awaiting to be filled with knowledge from a clever lecturer (Slater & Adams, 2003). Rather, students carry with them entire lives' worth of experiences, perceptions, attitudes, and knowledge that already informs an individualized physical or astronomical worldview. While this worldview may not be scientifically accurate, learners will remain attached to it unless they are forced to contend with false explanations, misconceptions, or inaccuracies and reach a new, refined understanding of the world around them (Zeilik & Bisard, 2000). Informed by the discipline-based education research (DBER) communities, guidance for instructors has made significant inroads into collegiate teaching pedagogies. Learner-centered pedagogies (Slater & Adams, 2003; Prather, Rudolph, Brissenden, & Schlingman, 2009), peer instruction techniques (Fagan et al., 2002; Green, 2003; Prather et al., 2009), classroom materials like lecture tutorials (Prather et al., 2004), and audience response systems like iClickers (Duncan, 2006; Kay & LeSage, 2009; Hunsu et al., 2015) have all made noteworthy impacts on learners, both in assessable gains and in attitudes towards learning itself. Critical to these techniques' success is the active participation of learners with their own learning, rather than waiting for instructor-delivered knowledge to be passively absorbed.

Classroom studies lean heavily into topics like pedagogical strategies and the use of particular classroom materials to elicit learning gains. However, most of the past investigations into planetarium efficacy have focused on its capacity to increase the content knowledge of the learners who partake in the setting; noticeably fewer have investigated the teaching strategies made therein (Slater & Tatge, 2017). For example, comparison studies like Yu and colleagues (2015, 2016) remark upon learners receiving lecture instruction as part of the study (with their test groups all receiving the same lecture, but in different settings to isolate the planetarium visuals as the variable of interest), but the pedagogies used in this lecture remained unspecified (Yu et al., 2015; Yu et al., 2016). Small and Plummer (2014) suggested that children benefit from a combined planetarium-active learning instructional regime, but the study was restricted to a small number of child-aged learners learning about the motions of the Moon. Thus, we encounter somewhat of a disconnect between the bodies of education research in the two settings most associated with collegiate astronomy: the classroom, where research focuses on what and how instructors do; and the planetarium, where research focuses on what and how instructors show. Even though the planetarium is the less frequently used of the two settings (Everding & Keller, 2020), both are still components of collegiate instruction and investigation of the planetarium setting should include considerations of its classroom counterpart. Is how a lesson unfolds as important as what is shown as a part of that lesson? This study seeks to confront this proposition by answering the following research questions:

1. What are the characteristics of faculty and undergraduate learners making use of the planetarium environment?
2. Why do faculty choose to use or not use the planetarium environment in their curriculum?
3. What do faculty planetarium users perceive as the benefits and drawbacks of the planetarium environment and why do these faculty see them as such?
4. How does a typical day of instruction in the planetarium proceed and what makes it similar or distinct from the regular classroom environment?

THEORETICAL FRAMEWORK

The implementation of this study was built using the Learning Environment, Learning Processes, and Learning Outcomes (LEPO) conceptual framework (Phillips, McNaught, & Kennedy, 2012). This framework describes learning as the mutual interaction of instructors and learners with three cornerstone constructs: the environment (both physical and contextual) in which learning occurs, the processes that are used therein, and the outcomes which are produced and assessed. For this study concerning both classroom and planetarium environments, LEPO offers a broad, descriptive framework of learning appropriate to collegiate contexts without becoming too prescriptive about the specific environment or the processes and outcomes accompanying them (Phillips et al., 2012).

This study will restrict itself to formal collegiate learning environments, that is those in which learning occurs during the official execution of an undergraduate course. These environments are made to achieve instructor-defined or institution-defined course goals with learner progress being ascertained through assessments by the instructor, usually ending with a final summative assessment resulting in a letter grade or final score for each learner (Wellington, 1990; Slater & Tatge, 2017). Additionally, this study will follow both the in-dome and out-of-dome ends of the planetarium research spectrum posed by Plummer, Schmoll, Yu, and Ghent (2015), focusing on the planetarium as a place to improve learning and on how the planetarium and classroom environments compare.

This study will examine learning in two separate physical environments for comparison purposes to achieve our research goals: the classroom environment and the planetarium environment. The processes that occur in either space are assumed to be consistent with others found in American collegiate settings, such as those described by the Classroom Observation Protocol for Undergraduate STEM (COPUS) (Smith, Jones, Gilbert, & Wiemann, 2013), discussed in greater detail below under "Methods & Investigation." Similarly, the outcomes expected in either setting are assumed to be identifiable as belonging to one of the taxonomic groups common in describing learning outcomes (Bloom & Krathwohl, 1956; Krathwohl, Bloom, & Masia, 1973; Anderson & Krathwohl, 2001; Bixler, 2018). Excluding these assumptions for collegiate learning, our only restrictive assumption is that learning in these spaces is entirely formal.

For descriptive purposes in this work, we will use "environment" or "setting" to denote instances of learning combining an actual physical environment (classroom or planetarium) being occupied in the context of the formal learning procedure being attended to. "Space" will be reserved for considerations of the literal environment—the actual physical space being occupied.

METHODS & INVESTIGATION

To provide structure to our later analysis we have defined two principle research constructs derived from our guiding research questions. The constructs and their input questions are presented in Table 1. The first construct, the "calculus" of using the planetarium, is informative of the decision-making process that faculty instructors make when deciding where, when, or how to integrate the planetarium environment into their curriculum. Presuming that a college level classroom is more likely to spend most of its time in a regular classroom or lecture hall setting during the learning process, the decision to relocate a group of learners to the planetarium should follow some general decision-making framework where an instructor makes cost-benefit analyses concerning the planetarium environment against the classroom environment.

The second construct, discriminating the classroom and planetarium environments, is informative of the presumed differences between the two learning environments including the implied differences between the learning processes and learning outcomes, per the LEPO framework (Phillips et al., 2012). Some similarities between the environments should be expected, as the two learning environments are both contextually formal. These differences and similarities should be identifiable to an outside observer, but given our weak assumptions about how the learning process should unfold in either environment, a more general observation protocol should be preferred to a more specific one, thus our choice of the COPUS observation protocol (Smith et al., 2013).

Critically, we did not approach this study as an evaluation of the efficacy of instructional practices in either the classroom or planetarium environments-observed practices and behaviors might be indicative of particular practice archetypes or preferences, but this study made no effort to categorize them as declaratively effective or ineffective towards any particular desired outcome.

Guidance for the construction of this study came from previous investigations exploring planetarium use, specifically those that examined use through the lens of planetarium directors and instructors (Fraknoi, 2001; Croft, 2008; Plummer & Small, 2013; Everding & Keller, 2020). The structure of this investigation contained two portions: (1) a survey portion using an online instrument to collect data; (2) and an observation portion using a classroom observation protocol, pre-observation questionnaires, and post-observation interviews to collect data. Survey data collection is a commonplace tool in astronomy and planetarium education (Fraknoi, 2001, 2004; Small & Plummer, 2010; Everding & Keller, 2020), and allows for the bulk collection of responses from a wide range of respondents. Observational data is commonplace at the collegiate level for professional development, and instructors may inaccurately describe their own teaching methods using self-report instruments like a survey, so validated observation protocols may be used to collect an unvarnished measurement of instruction (Kane, Sandretto, & Heath, 2002; Ebert-May et al., 2011). Interview data provides more content rich discussion by directly interfacing with planetarium instructors that would not normally be emergent in survey-only or observation-only data sets (Plummer & Small, 2013; Everding & Keller, 2020).

Table 1. Research constructs of this study. Constructs were formed by considering the guiding research questions and were explored during the two portions of this study.

Research Construct	Guiding Questions
The "calculus" of using the planetarium	Why do faculty choose to use or not use the planetarium environment in their curriculum? What do faculty planetarium users perceive as the benefits and drawbacks of the planetarium environment and why do these faculty see them as such?
Discriminating the classroom and planetarium environments	Which kinds of faculty and undergraduate learners are making use of the planetarium environment? How does a typical day of instruction in the planetarium proceed and what makes it similar or distinct from the regular classroom environment?

Survey data was collected using the online Qualtrics survey platform and distributed using institution email. Faculty instructors from five of the institution's constituent colleges were invited to participate in the survey. The choice of colleges was made based on the variety of past planetarium users at the institution's planetarium (private communication with planetarium director) and from the planetarium content results in our recent nationwide survey study (Everding & Keller, 2020). All faculty, both those with past planetarium experience and those without, were invited to participate in this survey held during the fall of 2019. Faculty who had never instructed a class in the planetarium were directed to answer a shorter survey instrument, taking approximately five minutes to complete. Faculty who had instructed a class in the planetarium were directed to answer a longer survey instrument, taking approximately 15 minutes to complete. This longer survey instrument was also used to roster participants in this study's observation portion.

The observation portion of this study was completed in two stages. Six consenting faculty instructors were observed during two lessons, one in the classroom environment and the other in the planetarium environment. Due to scheduling constraints, three faculty were observed during the fall of 2019, and the remaining three were observed during the spring of 2020. The pseudonyms of our observed faculty, a brief description of their respective courses, and the approximate number of enrolled students are shown in Table 2. Faculty participants chose the days they would be observed but were asked to pick days that could be described as "usual" or "typical" lessons such that our observations would minimize recording any spurious or unnecessarily singular interactions that would not be meaningfully representative of a lesson in either environment.

This study investigated the use of one specific planetarium by the surveyed faculty, which we will describe here. The planetarium comprises a 206-seat theater with the seats arranged in an epicentric pattern with the inclination of the seats focusing an audience's attention to a "sweet spot" approximately 30° above the dome's perimeter. Beneath the sweet spot is an elevated stage for a speaker to stand on if desired—the navigator's booth is opposite the stage and contains the controls for the planetarium's audio and visual systems. The line connecting the stage to the navigator's booth divides the audience approximately into halves. The theater possesses a hybrid projector system, with both an analog star ball projector and a digital fulldome projector. The analog projector occupies the center of the room and is surrounded by a central walled pit that separates the projector itself from the audience and impedes free movement through the central portion of the dome. The digital projector is composed of multiple projectors mounted around the perimeter of the dome and coordinated by the navigator's computer. Audiences may enter or exit the theater through two antechambers, each on opposite sides of the theater. The antechambers are meant to separate the well-lit lobby of the planetarium from the darkened environment of the theater, so audiences are not disturbed by brief, vision-impairing bursts of bright light during a show.

Table 2. Pseudonyms of this study's observed faculty participants along with descriptions of each participant's course and approximate enrollment. All observed faculty were members of the same university department.

Pseudonym	Course description	Approx. number of students
Dr. Monday	Non-major, non-sequenced introductory astronomy. Lower division. University's analog of "ASTRO 101."	200
Dr. Tuesday	Non-major, sequenced introductory astronomy. Lower division. Similar material domain as "ASTRO 101." Has a lab component.	200
Dr. Wednesday	Non-major, non-sequenced intermediate astronomy course concerning exploration of life in the Universe. Lower division.	120
Dr. Thursday	Non-major, non-sequenced intermediate astronomy course concerning space exploration and policy. Lower division.	100
Dr. Friday	Major-track, sequenced "ASTRO 101." Focuses on the nature of science, naked-eye astronomy, and planetary science. Has lab component. Lower division.	100
Dr. Saturday	Non-major, non-sequenced introductory astronomy. Lower division. University's analog of "ASTRO 101."	200

Observation protocols are powerful tools in the classroom learning environment, both for instructor reflection and education research on class practices (Sawada et al., 2002; Hora & Ferrare, 2013; Smith et al., 2013; Lund et al., 2015), but to our knowledge there has yet to be a study using these tools in the collegiate planetarium environment. COPUS was selected as the in-class data collection instrument for the observation portion of this study. Developed to provide an efficient and validated means of measuring classroom behaviors and procedures, COPUS characterizes the behaviors of both instructors and students using a set of 26 codes, 13 codes for each group. Codes are descriptive of particular actions, behaviors, or interactions within a collegiate STEM course—we direct the reader to Smith et al. (2013) for the full description of the observable codes. As is raised by Hora and Ferrare (2014), coding schemes can accidentally hide instructional behavior nuances by using overbroad codes that try to cover too many behaviors at once, so research concerning collegiate education should use a protocol that is as descriptive as possible. However, given the lack of prior guidance concerning observations in a planetarium environment and the desire to not prescribe that a particular style of instruction would occur in either the classroom or the planetarium environments, we decided against protocols like the Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002) or the Teaching Dimensions Observation Protocol (TDOP) (Hora, 2013).

Measurements occur in successive two-minute windows of time during a lesson. If a behavior is observed within a given two-minute window, that code is assigned to that block of time-if not, no assignment is made for that code (Smith et al., 2013). In addition to the 26 behavioral codes, COPUS also includes a metric to measure student engagement during each two-minute window. However, given the heavy reliance on visual cues which are difficult to discern in the darkened planetarium and the more subjective nature of determining student engagement, we decided to not use the three engagement codes for this study.

Rather than exclude the engagement coding framework completely, we adapted the three engagement codes in the protocol as a rough measure of illumination conditions during each observation. This study involves comparison between two physical environments (one of which presumably maintains low-light or zero-light conditions), so during each 2-minute window, the ambient lighting was recorded as either low (L), medium (M), or high (H) using the same recording procedure as the engagement codes. The rough framework used to determine which lighting level to record in the two environments can be seen in Table 3. Lighting conditions were determined by considering the illumination intensity of dedicated lighting fixtures, not incidental illumination caused by projector screens or fulldome projections.

Table 3. Repurposing of the COPUS engagement coding framework to record illumination conditions during the observed lessons.

Original COPUS Code	Repurposed Code	Description of New Code
Engagement - H	Lighting - H	Lights are "up" or at maximum brightness. An example would be a well-lit classroom during lecture or a planetarium theater with the lights around the dome on full intensity.
Engagement - M	Lighting - M	Lights are dimmed and/or chromatically altered to conserve low-light visibility. Examples include dimming a classroom's lights to darken the area near a projector screen or turning on low-intensity red lights in a planetarium.
Engagement - L	Lighting - L	Lights are fully "down" or completely off-blackout or pitch-black conditions.

As this study was not meant to explore or refine COPUS itself, but rather to investigate with COPUS, efforts were made to preserve as much of the original code scheme as possible without unnecessarily innovating new protocol codes. These efforts were of particular import in the planetarium environment, specifically with regards to the use of the planetarium's projection systems and the DV instructor code. DV, or "Demo/Video," is descriptive of instructors using experimental demonstrations, simulations, videos, or animations as a part of their lesson (Smith et al., 2013), which fits the description of using the planetarium projector reasonably well. However, as the planetarium dome is also equipped with a standard, flatscreen projector like ones found in lecture hall spaces, a distinction needed to be made as to when a particular projection shown to students qualified as DV. Since the regular classroom space is usually lacking in a fulldome planetarium projector system, innovating a new code specific to using a planetarium projector would have been impractical as no comparator code would exist in the classroom observations, so preserving the DV code structure was desired. For this study, the assignment of DV was made when either the fulldome or analog starball projection systems were being used to provide an immersive visual presentation. In situations where fulldome projection was not being used but rather standard 2D slides, the assignment of DV was not made. In such scenarios where instructors were using regular slides in the planetarium, the Lec instructor code ("Lecture") was assigned, just as if it was a slide presentation in the classroom space. Due to the temporal width of each observation window, it was possible for both DV and Lec to be coded in the same two-minute bin.

COPUS observations in both the classroom and planetarium environments were recorded digitally using the Generalized Observation and Reflection Platform (GORP), an online data collection platform hosted by the University of California Davis (https://gorp.ucdavis.edu/). The GORP platform uses a system of selection icons to record the behaviors measured by COPUS, with the set of selected icons automatically saving and resetting every two minutes to keep with the COPUS recording procedure (Smith et al., 2013). Observations in the two environments were made from the back of each classroom environment and from the navigator's booth in the planetarium environment. Between the six instructors, four unique classroom spaces were used, with two pairs of instructors sharing the same physical classroom space. Classrooms ranged from medium-sized (~100-seat capacity) to large-sized (~200--300 seat capacity). The same planetarium theater (206-seat capacity) was used for all six instructors. Only in-person observations were made for this study—video recordings of planetarium lessons were too difficult to produce in the darkened planetarium environment and trying to overcome that optical limitation could have unduly disrupted the observed lessons. Additionally, audio recordings were omitted from this study's design in an effort to be as unobtrusive as possible when observing lessons in either environment.

Compiling COPUS data was done by correcting miscodes that were accidentally or mistakenly made during each observation, with typical miscodes occurring due to the GORP platform automatically saving a miscoded behavior before it could be removed by the observer. These miscodes were identified by comparing handwritten observer notes made contemporaneously with each observation and correcting the observation record accordingly. Additionally, a period of approximately 10 minutes (five observation windows) was removed from the COPUS data for Dr. Friday's classroom observation-this 10-minute period was an unavoidable time where the students were completing an institutionally obliged faculty evaluation questionnaire.

Supplementing the COPUS protocol, each instructor was asked to complete a standardized pre-observation questionnaire before each observation period. These questionnaires tasked the instructor to describe the material they intended to cover during the observed lesson, outline their goals or outcomes, and what preparations had been made by the instructors or their students to achieve those stated goals or outcomes. Additionally, a post-observation interview with each observed faculty was conducted after both observations were completed. Interviews were conducted as soon as possible after the COPUS observations, usually a day or two after the second observation. Interviews were conducted in the campus offices of each faculty participant, with each interview taking approximately one hour to complete.

DATA & ANALYSIS

In this study, we present some of our data using box plots. To avoid any uncertainty of how we are using these presentation tools, we specify here how each box element is rendered. Each box is representative of a distribution of data points such that each box is rendered with the lower and upper box edges defined by the respective lower (Q1) and upper (Q3) quartiles of the data, with the intervening space between them being shaded. This shaded space is the interquartile range (IQR), with the horizontal white lines denoting the median (Q2) of the data. The sloped notches beginning on the median in each box denote the 95% confidence interval (CI) of the median for the presented data, with the transition to vertical sides denoting the end of that 95% CI—for many of our presented boxes, the notches span the entire box, indicative of a widespread in the presented data. The lower fence (a horizontal line) is placed on the smallest data value between Q1 and 1.5*IQR below Q1; the upper fence is similarly defined using the largest data value and Q3. The two fences bound the space containing all of the meaningful data within a given distribution-all data in a distribution outside this fenced boundary are considered outliers and are plotted as individual points (Krzywinski & Altman, 2014).

This study investigated both faculty instructors who used the planetarium environment as well as those who did not. For the sake of convenience, we will refer to faculty with past planetarium use experience as "users" and those who have not as "non-users." Rather than present all this study's data at once, we will present data products as they are used to explain this study's research constructs (Table 1).

Construct 1: The "Calculus" of Using the Planetarium

The "Calculus" Of Non-User Faculty

To confront our first construct, we began with our probe into why faculty might not use the planetarium environment, investigated using this study's short-form survey. Non-users were asked to select reasons why they had yet to include a planetarium in their curricula from a predefined list of options, each describing a particular barrier against planetarium use. Participants could select as many options as they felt appropriate, and participants could also provide their own reasons in a fill-in-the-blank box if they felt none of the predefined barriers adequately described them, though none did. The five non-user archetypes presented below represent a roughly hierarchical progression of barrier complexity, beginning with the simplest barrier, awareness of the planetarium (A), and ending with the most nuanced barrier, procedural or administrative difficulties (PrAd). Where appropriate, barrier archetypes were subcategorized to explore differing dimensions within each archetype. The five non-user barrier archetypes (and associated sub-archetypes) provided can be found in Table 4.

Table 4. Response archetypes investigated for non-user faculty instructors ($N = 88$). The percentage of non-users who chose each archetype is shown in the right-hand column, rounded to the nearest percent. Standard counting error is assumed in each response bin ($\sigma_k = \sqrt{N_k}$). Respondents could pick as many options as they felt appropriate to describe themselves, so percentages will not sum to 100%.

Usage Barrier Archetype	Sub-Archetype	Percent of Non-User Respondents
Awareness of Planetarium (A)	A1: Did not know planetarium exists	1 ± 1
	A2: Did not know planetarium could be used by any faculty at the institution	32 ± 6
	A3: Had not considered the environment before, but knew of existence and possible use	65 ± 9
Logistics of Planetarium Lesson (L)	L1: Knew of planetarium, but had not explored the uses of the environment	30 ± 6
	L2: No time for class to make trip to planetarium, regardless	7 ± 3
Financial Constraints (F)	F: Monetary restrictions existed against using the planetarium	6 ± 2
Presentation of Content (P)	P1: Unknown if appropriate subject matter exists to be shown	56 ± 8
	P2: Existing content is too sparse or nuanced	0 ± 0
Procedural / Administrative Barrier (PrAd)	PrAd1: Had considered using planetarium, but had not reached out to try	10 ± 3
	PrAd2: Had tried to use planetarium in the past, but encountered difficulty coordinating	0 ± 0

Characterizing the non-user responses (Table 4) suggested that the major barrier impeding planetarium use is either not considering the planetarium environment as a possible venue (A3) or not knowing if appropriate subject matter exists for their instructed subject (P1). The first of these major barriers, A3 (65% of respondents), is indicative of non-users assigning limited value to the planetarium environment for their discipline. This barrier may be suggestive of the planetarium being "guilty by association" with astronomy content. Instructors from another subject field like chemistry might never need to consider the planetarium, because the planetarium is perceived to be an exclusive place to instruct astronomy. This astronomy associated barrier is given further weight when considering the noteworthy percentage of the L1 barrier (discussed separately below). The second major barrier, P1 (56% of respondents), is suggestive of a lack of communication or lack of marketing between the planetarium, content producers, and prospective instructors.

The A3 and P1 barriers are not unexpected as the most prominent measured in this question. Historically, the planetarium's association with astronomy content was a matter of technological practicality-in fact, almost all past planetarium research has used astronomy content as the learning medium of choice (Slater & Tatge, 2017). Prior to the widespread installation of digital planetariums, presentations in a planetarium relied upon older, analog-only starball projectors and static slide projectors to present visuals to the audience. Content that did not make effective use of these presentation tools (particularly the starball projector) was likely not considered cost-effective to show in the planetarium theater. However, the steady installation of fulldome digital projectors (Wyatt, 2005; Yu, 2005) coupled with the progressive diversification of fulldome content development would suggest that planetariums be relieved of their perceived exclusivity to astronomy content instruction (Everding & Keller, 2020). The potential of the immersive learning experience in a planetarium has been demonstrated to benefit undergraduate students in astronomical contexts (Yu et al., 2015; Yu et al., 2016; Yu et al., 2017); but, immersive content for the fulldome planetarium that does not center on astronomy has been produced for some time (e.g. Dynamic Earth, Expedition Reef, The Body Code, Supervolcanoes, Exploring Limits, The Green Planet 3D, or Whale Superhighway (FDDB: Fulldome Database, 2020). Using the innovation-decision process framework presented in Rogers (2003), these results are indicative of an inefficient or ineffective communication channel between the planetarium stakeholders (directors, content creators, etc.) and instructors not already using the planetarium environment. In spite of the advancements offered by the planetarium environment, non-user faculty have not been made aware of them (knowledge-level communication) or have not been convinced of their usefulness (persuasion-level communication) as instructional implements (Rogers, 2003). Communications may need to be re-examined and possibly recrafted to better “sell” the planetarium, as instructors do not appear to quickly or regularly attempt to integrate new technologies in their pedagogical framework (Hora & Holden, 2013). Planetarians and content creators seeking to diversify the variety of college classes instructed in the planetarium space may want to direct communications towards specific academic departments, rather than to university-level administrators (Kezar, Gehrke, & Elrod, 2015; Matz et al., 2018).

Two minor barriers (A2 and L1) amounted for 32% and 30% of respondents, respectively, considerably fewer responses than A3 or P1. The first of these, A2, represents a straightforward barrier-instructors did not know they could use the planetarium. Taken with the discussion above, A2 could indicate an imperfect communication channel like the one described above for A3 and P1. The second, L1, represents a concept similar to A3, but describes an instructor that has made a minimal consideration of the environment, but has been otherwise prevented from exploring the environment due to resource constraints concerning how a lesson might actually unfold. The L1 barrier alone could suggest that the planetarium environment is a more novel consideration than other pedagogical innovations, and that instructors who are open to the idea of the planetarium environment may benefit from assistance in turning the idea of a planetarium lesson into a reality. We contend that this barrier rests somewhere between persuasion-level communication and decision-level communication, suggesting that L1-identifying instructors are “almost there” in being convinced of the planetarium’s usefulness (Rogers, 2003). Coupled with the low counts from L2, L1 suggests that non-user instructors by-and-large would have no trouble getting their students physically into the planetarium but would face a higher barrier in deciding what to do once their class was there. The remaining barriers offered to the respondents did not record substantial returns and are not discussed further here.

The “Calculus” Of User Faculty

Next, we present our probe into why faculty do use the planetarium environment as a part of their curriculum. To answer this question, respondent faculty were asked five free-response questions during the long-form version of the online survey. These questions asked the respondents to explain: (1) why they used the planetarium at particular times during the academic term; (2) why they chose to incorporate planetarium visit into their curriculum; (3) what outcomes they expected their students to reach; (4) their own cost-benefit analysis to using the planetarium; and (5) how a typical lesson in the planetarium unfolds for their classes. The responses to these five questions were aggregated and coded in concert-a brief analysis of the responses showed that some respondents answered parts of one question in the response to another, thus combining all five during coding preserved the necessary information.

Unlike the non-user barriers described above, the coding analysis of the user responses was a mix of predefined (code classes E, T, and W) and emergent codes (code classes S, C, L, and F). Emergent codes were created and revised as needed to describe the responses as accurately as possible - emergent codes that did not merit at least 10% of users were discarded or reincorporated into larger codes.

We first discuss our three predefined codes in Table 5: E, T, and W. Code E (outcome-based choice of environment) is illustrative of what instructors described as the outcomes they wanted their learners to achieve by attending instruction in the planetarium. Outcome identification was completed by analyzing instructors’ responses and comparing their use of particular verbs and nouns to the key-word descriptions of the affective (code E2) and cognitive domains (code E1) (Bloom & Krathwohl, 1956; Krathwohl et al., 1973; Anderson & Krathwohl, 2001; Bixler, 2018). A minority of respondents described both the affective and cognitive domains (E1 and E2) in their desired learner outcomes (code E3) - counts of E3 are the subset of individuals who are already counted in both E1 and E2. The two remaining codes were assigned to responses that specifically cited the environment as a complement to the regular classroom (code E4) and when instructors described the planetarium as “cool,” either in their own capacity or attesting that description to their learners’ experience (code E5). We make a brief note here of E5, given the possibility of overlap with the affective domain code E2. E5 exists as a separate code due to the implication of words like “cool” or “exciting” in the context in which they were provided by respondents, the implication being that their learners were entertained by the planetarium experience. We do not doubt that entertaining lessons are possible vehicles for outcomes like those described by codes E1 and E2; however, entertainment is not an outcome per se.

Table 5. Coding scheme of the user responses ($N = 22$) concerning why/how/when they incorporate a planetarium into their curriculum. Four responses were left blank or were otherwise not adequate for analysis. Standard counting error is assumed for discussion ($\sigma_k = \sqrt{N_k}$), but not included in each presented bin. Asterisks (*) denote predefined codes; daggers (†) denote emergent codes; ampersands (&) denote the intersection between two other sub-classifications.

Code Classification	Sub-Classification & Description	Number of Users	Percent of Users
Outcome-based choice of environment (E)*	E1: Cognitive gain/outcome	12	54.5%
	E2: Affective gain/outcome	10	45.4%
	E3: Both E1 and E2&	5	22.7%
	E4: Complement to classroom material/environment	11	50%
	E5: Planetarium is "cool," "exciting," "interesting," etc.	11	50%
"Seeing It" (S)†	S1: Stresses immersive experience	5	22.7%
	S2: Shows/animates "how things work"	9	40.9%
	S3: Information shown in different or alternate ways compared to classroom	6	27.2%
Specific content referenced (C)†	C1: Sky motions (daily/annual/etc.) or closely related	10	45.4%
	C2: Other content	14	63.6%
	C3: Both C1 and C2&	8	36.3%
	C4: C2 with astrophysics-centered content	8	36.3%
	C5: C2 with planetary science-centered content	5	22.7%
Typical lesson description (T)*	T1: Describes an augmented classroom setting	9	40.9%
	T2: Describes film/movie/cinema	0	0%
	T3: Describes a "lecture-only" setting	7	31.8%
	T4: Both T1 and T3&	5	22.7%
	T5: Other learning experience (studio/exhibition/etc.)	3	13.6%
Learner types/experiences distinguished (L)†	L: Describes benefits applying to different, defined groups of learners	4	18.1%
Costs associated with using planetarium (F)†	F1: Logistical cost (e.g., movement of learners to planetarium)	6	27.2%
	F2: Pedagogical cost (e.g., no notes in darkness or difficulty delivering lesson)	4	18.1%
	F3: Specifically refutes idea of a cost	4	18.1%
When to incorporate planetarium (W)*	W1: Planetarium use meets specific content delivery goals	17	77.2%
	W2: Planetarium use meets specific calendar dates	4	18.1%

Counts of E1, E2, and E3 suggest no particular preference towards either outcome domain across the group of surveyed instructors; assuming standard counting error ($\sigma_k = \sqrt{N_k}$), E1 and E2 are not distinguishable from one another and E3 is a distinct minority. This collection of count trends suggests that neither outcome domain was seen as clearly preferable for users; thus, the counts for codes E1-E3 did not uniquely explain why the planetarium space was used in terms of desired outcomes. However, counts from E4 and E5 offered possible insight into why the environment is used. Half of the respondents were descriptive of their use with specific reference to the classroom environment, either by referencing specific pieces of classroom content or referencing the classroom setting generally. Similarly, half of the respondents expressed that the planetarium environment is "cool" or "exciting," either by their own estimation or as had been expressed by their past planetarium learners.

These counts suggest that the reasoning for users contained both a content-specific consideration (codes E1--E3), but also a "coolness" value judgement that went beyond the normal constraints of classroom outcomes. This might imply that instructors using the planetarium as a formal learning environment are making similar value judgments about the setting as planetarium professionals who generally create informal learning environments. Specifically, users are making judgments about the planetarium with the clear goal of educating, but also wanting to leverage the setting to inspire their learners to continue learning or exploring after the presentation ends (Croft, 2008; Small & Plummer, 2010; Plummer & Small, 2013).

Such a value judgment might not be inappropriate for users to make, given that holding a lesson in the planetarium does require additional administrative and logistical concerns that the classroom does not. However, it could suggest that instructors are knowingly presenting course material in a different, more informal context when moving to the planetarium space during the execution of a formal collegiate course. Learners in informal environments are typically responsible for their own learning with little-to-no expectation of an assessment after the learning period is completed (Wellington, 1990). Informally presenting planetarium content as a part of formal instruction might cause a conflict of expectations between instructors and learners, possibly hampering learning (Marshall & Linder, 2005). Instructors might present content in so informal a manner that learners feel relieved of their responsibility towards meaningfully confronting the content. In the worst-case scenario, learners might consider the planetarium a "zero-stakes" environment and participate in distracting behaviors like talking or sleeping (Everding & Keller, 2020).

Code T (typical lesson description) is illustrative of how instructors described the procedure and delivery of their planetarium lessons. Three archetypes were presupposed as to what an instructor might describe as their typical lesson, each of which has characteristic qualities that help distinguish it from its companions. Code T1 describes a lesson resembling the regular classroom with mention of the planetarium's technology. Usually included are mentions of classroom procedures or materials like lecture slides, the use of the planetarium's iClicker system, and the collection or distribution of material like homework or worksheets. Code T2 describes a lesson resembling a visit to a movie theater or cinema, described through express mention of playing particular fulldome films or a learner audience that would look identical to a group of general public moviegoers. Code T3 describes a lesson resembling a lecture-only setting, usually through mentions of a presentation that is almost entirely presenter or content focused with few mentions of audience interaction or typical classroom materials like those described under T1. The potential overlap between T1 and T3 is evident from their descriptions, given that many facets of each code have some similarity in the other-we discuss the differences between the two below. This crossover between the two is highlighted in code T4, where an instructor's description of their lesson had aspects of both T1 and T3. Finally, code T5 represents a described lesson that doesn't fit well into any other group, usually describing something like an exhibition or a conference poster session where the environment is not definitively formal or informal.

Lecture-only settings (T3) and augmented classroom settings (T1) do share procedural similarities like a primary lecturer presenting content to an audience in a formal setting; however, the two settings do maintain exclusive aspects that help distinguish them from one another. Chief among the exclusive aspects is the implied behaviors of the learner audience in the two settings. In T1, the implied behaviors of the learners are more active, engaging and interacting with the instructor to reach the lesson's desired outcomes. In T3, the implied learner behaviors are passive, with learners only responsible for listening and paying attention. The high degree of overlap between T1 and T3 could suggest a planetarium lesson that blends the procedures from an interactive classroom with a lecturer-centered classroom. We explore this implication in greater detail below in "Construct 2."

Code W (when to incorporate planetarium visits) is illustrative of when in the course of their overarching semester lesson plan an instructor chooses to make use of the planetarium. Two types of "when" were considered when defining the two subcodes for W. Code W1 describes a more figurative "when" that is defined by the arrival of content within an academic semester, i.e., the class has reached a particular body of content or knowledge that is seen as usefully instructed in the planetarium. Code W2 describes a more literal "when," and is denoted by the use of calendar dates or events not ascribed to bodies of content. For example, an instructor who uses the planetarium to present sky motions in concert with the progression of course content would be denoted with W1, but an instructor who uses the planetarium when they are personally or professionally away from campus would be denoted with W2.

The distribution of W codes is rather one-sided, with 77% of respondents describing the "when" of their planetarium use as occurring when particular content is encountered during the course of the academic term, as opposed to particular calendar dates during the term (described by 18%). Since a course's schedule for an academic term (i.e., the syllabus layout or calendar) is likely written in advance of the course in question, it follows that planetarium use is not likely a spontaneous affair at the collegiate level. Rather, a user who has defined their content goals for their course must then decide which of these content goals will be presented in the planetarium well in advance of the actual presentation. Additionally, by scheduling a visit so far in advance, the actual learners who will experience a lesson in the planetarium would have given no input as to what would actually be presented during that visit. However, since learners are likely to struggle with the same concepts term after term, an instructor using their past teaching experience to schedule future planetarium visits is likely a sound decision. Lastly, this administrative necessity of scheduling visits well in advance of their occurrence might unduly hamper innovation in the planetarium environment, or at the very least dissuade users from trying new pedagogies or content presentations. If the availability of the space is likely to be limited, a user may not deviate from well-established or well-practiced instructional patterns in the space since chances to revisit or revise such patterns do not happen within a reasonable time. We note for the reader that this administrative process of scheduling planetarium visits well in advance of actual visits may or may not be commonplace in other college or university settings.

We will now discuss our four emergent codes shown in Table 5: S, C, L, and F. Code S ("seeing it") is illustrative of instructors using the planetarium for its visualization capacities, literally allowing their learners to "see" a body of content that might not otherwise exist in such a format. Code S1 describes instructors who specifically cited the planetarium's immersive projection capacity. Code S2 describes instructors citing the ability to animate or actually show particular effects or motions in the planetarium theater, typically to show "how things work." Code S3 describes instructors who specifically noted how the planetarium compares and contrasts with the classroom as a content delivery environment for their lessons.

S1 focuses the power of the planetarium upon its arguably most unique trait as a learning environment-the ability to produce immersive learner experiences for students. The benefits of immersive learning are well described across numerous modes of presentation like planetarium theaters (Sumners et al., 2008; Price, Lee, Subbarao, Kasal, & Aguilera, 2015; Chastenay, 2016), virtual-reality (VR) platforms (Donalek et al., 2014), and even interactive crime scenes (Bassford, Crisp, O'Sullivan, Bacon, & Fowler, 2016). S2 stresses the animation qualities, which may or may not themselves be immersive. Animation provides learners assistance by showing "how something works," and the learning benefit provided by animations is described across broad educational contexts (Yang, Andre, Greenbowe, & Tibell, 2003; Rebetez, Bétrancourt, Sangin, & Dillenbourg, 2010; Berney & Bétrancourt, 2016); however, animations are not entirely understood as to the precise mechanisms that aid learning when they are used (Schnotz & Rasch, 2005; Kriz & Hegarty, 2007; Castro-Alonso, Ayres, & Paas, 2016). S3 could be the most critical emergent code of our survey respondents, as this code reinforces the idea that the planetarium does not exist as a truly separate setting from the classroom, but is seen as an integral piece of the whole, as discussed above for code E. S3 could suggest that for the purposes of undergraduate education, the classroom/planetarium pair may be uniquely powerful in confronting learner misconceptions by granting learners two settings in which to confront material, similar to computer simulation experiences (Smetana & Bell, 2012). Such an attitude towards the planetarium highlights a prospect from astronomy education that we feel needs greater consideration-the planetarium as a laboratory setting (Fitzgerald, Bartlett, & Salimpour, 2019).

Laboratory classes provide additional opportunities for learners to confront course materials in a "hands on" setting with greater social aspects than the classroom environment (McCrady & Rice, 2008). Unlike experimentation-driven disciplines like physics or chemistry, observations drive astronomy, and most astronomical observations require prohibitively expensive equipment (Marschall, 2000). Disciplines like physics are usually replete with experimental setups for a physics laboratory course to choose from, but astronomy laboratories have comparatively limited options (Fitzgerald et al., 2019). Like computer simulators (Marschall, 2000), digital planetariums might offer a feasible work-around by simulating astronomical phenomena that can then be confronted by learners. Learner-driven exercises like the manipulation of three-dimensional astronomical orrerys on a tablet computer have shown gains when learning about astronomical sizes and scales (Schneps et al., 2014), and direct interaction by students with a zoom-in/zoom-out interface has been suggested as aiding learners grasp of sizes and scales normally beyond everyday human experience (Magana, 2014). With appropriate technical assistance, learners might use the planetarium in a similar fashion "hands on" for laboratory exercises, enhancing learners' agency with the environment and allowing more impactful confrontation of misconceptions (Bakas & Micropoulos, 2003).

Code C (specific content referenced) is illustrative of what concrete content examples instructors chose to provide when describing what they showed in the planetarium during their lessons. Code C1 describes the "usual" use of the planetarium, e.g., showing sky motions like the diurnal, monthly, and annual motion of the celestial objects in the sky, naked eye observations, or other ground-based, technologically unaided sky observation. Code C2 is the contextual complement to C1, describing content that does not fall into C1, including a wide span of content ranging from the surface of Mars to the edge of the observable Universe. Code C3 describes instructors who overlap both C1 and C2 in their descriptions. Codes C4 and C5 split C2 into two broad categories of "other content." C4 is descriptive of astrophysical content like the scale of the Universe, the exploration of black holes, and "flying" through the Milky Way Galaxy simulation. C5 is descriptive of planetary science content like examining other planets (including exoplanets), "flying" though the Solar System orrery simulation, and visiting the surface of Mars. C4 and C5 are not mutually exclusive for a given instructor-if an instructor described other content that qualified as both astrophysics-centered and planetary science-centered, they were marked as both C4 and C5. Lastly, not all content was describable by C4 and C5, but since no broad theme was emergent from these final descriptions, they have been left incorporated into C2. Assuming standard counting error ($\sigma_k = \sqrt{N_k}$), C1 and C2 aren't distinguishable from one another, and the overlap between the two is substantial (C3). This distribution of C subcodes highlights that planetarium users continue to attach high value to the planetarium's classical instructional uses (like sky motions and naked-eye phenomena) and that value is similarly attached to the technology-dependent materials that need digital fulldome projectors (like "flying" and 3D simulation).

Code L (learner types/experiences distinguished) is the smallest of the emergent categories but does highlight a point worth mentioning. L is illustrative of instructors who expressed some kind of discrimination in their descriptions of planetarium use based on what particular class they were instructing (e.g., "ASTRO 101" compared to "ASTRO 400"). The low number of L counts suggests that instructors using the planetarium do not see the need to distinguish between learners of different experience levels when considering the use of the planetarium but may rather be relying upon a different decision schema that may be based upon presented content. We continue our discussion of the implications of code L below in Construct 2.

Code F (costs associated with planetarium use) is illustrative of instructors who expressed some kind of cost or tradeoff (or lack thereof) in using the planetarium for their lessons. Code F1 describes a logistical cost in using the theater, like needing to relocate a class to the planetarium theater. Code F2 describes a pedagogical cost incumbent in planetarium use, like learners not being able to take notes in the theater or being restricted in their personal movement through the space due to the orientation of the audience. Code F3 describes instructors who countermanded the premise of the question, and specifically mentioned there being no cost towards their use of the planetarium in their lessons, logistical, financial, or otherwise. Interestingly, three of the four (75%) F3 responses also counted as E5, possibly suggesting that their use of the planetarium is satisfactory, so long as an entertaining experience is had by their learners. None of the three F codes are distinguishable from one another, assuming standard counting error ($\sigma_k = \sqrt{N_k}$); however, the theme of the two material codes (F1 and F2) does highlight a particular difficulty that users may encounter that are worth discussing.

F1 represents a cost not likely typical to the usual classroom setting, namely the cost of movement to the space. College classrooms are identified and assigned by administrators well in advance of an academic term, let alone an individual lesson, and the classrooms themselves are likely not prone to switching, barring some externally imposed need. The planetarium space is likely not one of these regular spaces and exists functionally outside the regular assignment framework for a college. As such, for classes that do not routinely meet in the planetarium (or in the most extreme case, only meet in there), learners will need to relocate to the planetarium, which may not be at a location as readily accessible as another building on campus. When there, more time is needed to get seated and situated, delaying the start of class. As late-arriving students make it to the planetarium theater (mostly at the beginning of class), the presentation must be temporarily paused so learners are allowed into the theater and situate themselves. As a consequence, college classes in the planetarium are likely to be temporally shorter than their classroom counterparts (similar to Plummer et al. (2015) statements concerning visits to informal planetarium learning settings), meaning the true cost described by F1 is actual class time.

F2 is representative of the planetarium space being incompatible with an instructor's preferred presentation style, specifically how the planetarium space does not oblige particular actions, strategies, or techniques that would be available to an instructor or their learners in the regular classroom. Examples mentioned by our respondents include actions like moving among learners during group discussions or being able to have learners take notes on the content shown in the theater. If an instructor views such activities as necessary to reach their course goals, but they are unable to do so in the planetarium, then they might feel compelled to have their learners "make up" those activities in the classroom setting rather than attempting to include them in the planetarium. Like F1, the true cost of F2 is time, but rather than being a cost of time in the planetarium, F2 is instead a cost of time in the classroom.

Complementing our user survey responses, we now discuss the post-observation interview responses from our six observed instructors. Given the small number of interviews, a coding scheme like the one in Table 5 was not advisable for analysis. As such, we will discuss our interview responses in a holistic manner such as the interview discussions presented in Croft (2008) and Everding and Keller (2020). Interview topics were contextualized for each interviewee based on their responses to their pair of pre-observation questionnaires; these topics and the group responses are shown in Table 6.

Table 6. Summary of post-observation interview responses from the six observed user instructors. Interview discussion topics are presented in the left column, and the holistic findings from interviewees are presented in the right column.

Post-Observation Interview Topic	Group Response Trends
Choice of material/content in each environment	Classroom described as the appropriate setting for "regular" classroom material like notetaking or calculation. Planetarium described as the appropriate setting for less strenuous course material not needing notes, calculations, or contemporaneous discussions. Described content-specific actions undertaken by learners suggest a more instructor-centered/passive-learner planetarium experience. Suggested instructors held an idea of "planetarium worthy" content.
Goals/outcomes in each environment	Classroom goals stressed low-to-mid level cognitive outcomes. Planetarium goals stressed low-level cognitive and affective outcomes. Classroom seen as favorable venue for cognitive outcomes; planetarium is seen as favorable for affective outcomes. Instructors encountered difficulties incorporating interactive strategies in the planetarium environment due to physical layout of the space. Planetarium outcomes required coordinating with a third party planetarium staff member to orchestrate learning.
Procedure to achieve goals/outcomes in each environment	Instructor preparation strategies for the two environments showed significant overlap (e.g., study notes or review/update old slides). Classroom preparations showed greater planning towards active-learner pedagogies compared to planetarium. Planetarium preparations seen as decidedly more time-intensive and focused more on what visualizations would be shown. Posits the existence of a "script" for the classroom environment that does not generally exist for the planetarium.

The response trends concerning the choice of materials/content in the two environments resulted in an interesting partition, seen in the first row of Table 6. Classroom material was typically well described in terms of how a particular lesson would unfold—specific action items like Clicker questions, board writing/note taking, or group discussions were clearly enunciated as a part of classroom material content. Conversely, planetarium material was well described in terms of what a particular lesson would contain - specific projections or animations like sunrise/sunset simulation, exocentric Solar System orrery projection, or fulldome pre-recorded movie content were mentioned. Content presentation that made use of note taking or class discussion was decidedly preferred in the classroom space, as the planetarium space was not considered conducive to these "regular" classroom activities due to the lowlight conditions and seating arrangement in the theater.

Critical among these responses was the emergent, if loosely defined, concept of "planetarium worthy." Content worthy of the planetarium generally centered on immersive projections not available in the classroom space. The immersive projections were seen as helping learners build a more complete understanding of the presented material and offering a complement to the presentation styles used in the classroom. Thus, "worthy" content fulfilled two principal traits, according to our observed instructors: (1) "worthy" content is capable of being rendered as an immersive visual experience; and (2) the content exists in another format in the classroom environment, such that the same underlying information can be present in both content presentations. Interviewees converged upon the idea that any content shown in the planetarium (the setting held to be non-conducive to regular classroom activities) must invariably be discussed or confronted again in the classroom setting, where regular classroom activities could touch upon said content. This confrontation in the classroom environment could happen either before or after confrontation in the planetarium. Incorporating our interviews with the discussions made by Yu et al. (2015) and Rau (2017), "worthy" content was characterized as follows. "Worthy" content was content which was presentable in a visually superior format in the planetarium (visually immersive and resolved); but, "worthy" content was also presentable in the classroom in a visually inferior format (non-immersive, like a projector slide), likely supported by deeper verbal discourse, textual accompaniment, or both.

Response trends concerning the goals/outcomes in each environment are seen in the middle row of Table 6. Described goals in the classroom stressed low-to-mid level cognitive outcomes, with no explicit mention of affective ones (Bixler, 2018). Goals in the planetarium were general low-level outcomes across both the affective and cognitive domains. Interview discussions helped distill these responses further, with instructors generally seeing the classroom setting as the appropriate venue for cognitive outcomes and the planetarium setting for affective ones. Described reasons as to why fell along the same lines of discussion concerning the course content discussed above. Instructors held that when their learners are stripped of the practical ability to take notes, make calculations, or engage in group discourse the ability of the lesson to achieve cognitive outcomes is stifled. Such mentally (and possibly physically) rigorous activities were thus held as more appropriate for the classroom setting. Desired affective outcomes were discussed as not necessarily needing these more rigorous activities, thus the planetarium would more naturally align with the affective domain; any cognitive outcomes that occurred in the planetarium were seen as positive, but were not the primary focus of the environment.

Difficulties described by instructors in reaching their enunciated goals fell mostly upon the planetarium. Classroom difficulties discussed were very nuanced and no group trend among these difficulties emerged. For example, Dr. Friday's classroom difficulties centered around time constraints and not being able to present all the desired content for that day's lesson. Conversely, Dr. Saturday's classroom difficulties centered on how a class-wide discussion technique did not unfold as anticipated. Planetarium difficulties across the group were more cogent. This group of instructors described a level of physical movement through the classroom space that is perceived as facilitating their preferred instructional styles (many of which were descriptive of reformed practices), but the planetarium's physical restrictions on movement (low lighting, crowded/cramped space) placed a pronounced hindrance upon them from presenting content in their classroom-practiced style.

The trends concerning the procedures in each environment are shown in the last row of Table 6. The described preparations for each lesson showed noteworthy overlap, with preparation strategies like reviewing or correcting old slide sets and studying content notes being common for the two settings. However, descriptions of classroom preparations made greater mention of planned reformed/active-learner practices like Clicker questions and group discussions than in the planetarium preparations. Unquestioned among the interviews was the perception of planetarium lesson preparation needing more time than classroom lesson preparation-this perception was emergent from all interviews, regardless of past user experience. Moreover, preparation for a planetarium lesson was seen as itself requiring the planetarium. All classroom material described in the interviews revolved around a set of slides that would be shown during a lesson—slides could be reviewed anywhere via a personal computer, so reviewing for a classroom lesson required little more than an instructor's computer and course notes. Planetarium preparation was seen as needing a rehearsal with a planetarium staff member in the planetarium environment - such a constraint on preparation required the coordination of a third party and was restricted to a single location on campus. Instructors were not pessimistic about this additional demand on their time, but all were able to identify it as a difficulty they encountered.

Unique among the interview points was the idea of a "script" for classroom lessons that did not generally exist in the planetarium. This script, typically the collection of lecture slides used during the lesson, "mapped out" the lesson's content into small, sequential quanta of information for both the instructor and their learners. This script thus provided a procedural framework that not only laid out the lesson's procedures but also served as part of the content delivery system. Fulldome visuals in the planetarium were not similarly discretized, and the "map" of a lesson could be more easily lost without the comparatively more ordered slide set framing the lesson delivery.

Synthesizing the analysis of this construct's data, the "calculus" of using the planetarium environment may now be described. An instructor considers a course's available content and determines if any would be "planetarium worthy." This worthy content is seen as benefiting the learners by being shown in two ways: as an immersive visual spectacle in the planetarium, shown without any contemporaneous "regular" classroom material (notes, calculations, discussions); and as a weak visual like a 2D projection in the classroom, where regular materials are available for the learners. These materials could be from the planetarium's well-established content profile (e.g., sky motions or Moon phases) or from its more recent, digital fulldome content profile (e.g., flying through the Universe). Visits to the planetarium are made around a course's content schedule, not around any individual personal schedule. Additional time must be allotted to preparing for a planetarium lesson in order to coordinate with a planetarium operator who will aid the instructor in delivering the lesson in question. Furthermore, lesson preparation must take into account a likely loss of class time as the planetarium space requires extra temporal expenditures like transit time to the planetarium and early-lesson interruptions to seat late arrivals.

Construct 2: Discriminating the Classroom & Planetarium Environments

Discriminating The Two Environments: Survey Responses

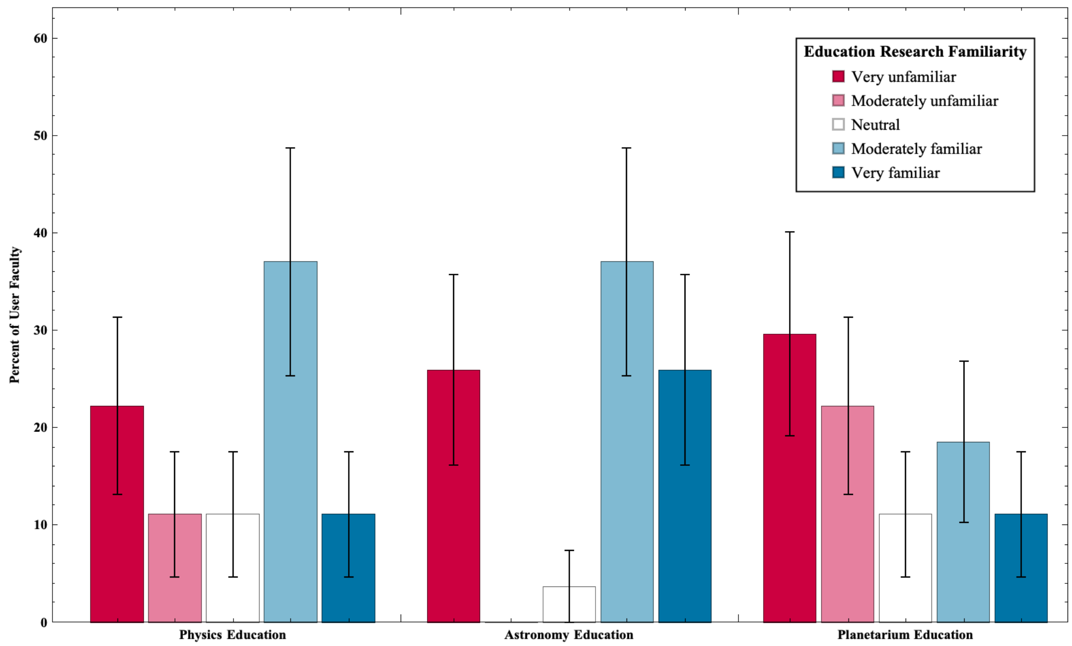
To confront our second research construct, we examined our respondents' self-reported prior teaching experience. Respondents were asked to identify how many years each had spent instructing at the various instructional levels common in the United States, ranging from pre-K to four-year university/college. By and large, survey respondents reported experience only at the university/college level, with minimal, but varied, experience at other instructional levels (Table 7). This trend holds when examining users and non-users as separate groups (not shown separately in table), with a Kolmogorov-Smirnov test failing to reject the null hypothesis that the two groups have the same distribution of collegiate teaching experiences at the 5% significance level ($\alpha = 0.05; U_{KS} = 0.167;\ p = 1.0$).

Table 7. Statistical measures of survey respondents' ($N = 113$) teaching experience across American instructional levels, measured in years. Results strongly suggest that none of this study's respondents have much experience outside the formal, university/collegiate context.

Instructional Level	Years of Experience		
	Mean ± St. Dev	Median	Range
University/college	15.3 ± 11.2	12	0 - 41
Community college / Junior college	0.2 ± 0.7	0	0 - 4
High school (grades 9--12)	0.5 ± 2.7	0	0 - 25
Middle school (grades 5--8)	0.2 ± 0.8	0	0 - 5
Elementary school (grades 1--4)	0.1 ± 0.6	0	0 - 4
Kindergarten or younger	0.1 ± 0.6	0	0 - 6

Respondents were also asked to rate their familiarity with the fields of education research (physics, astronomy, and planetarium) that typically confront the planetarium as an investigable venue of education. Respondents were allowed to enter another discipline-based education research (DBER) field they were familiar with (e.g., chemistry, biology, and engineering), but few did so. The reported familiarity with these fields amongst users is presented in Figure 1.

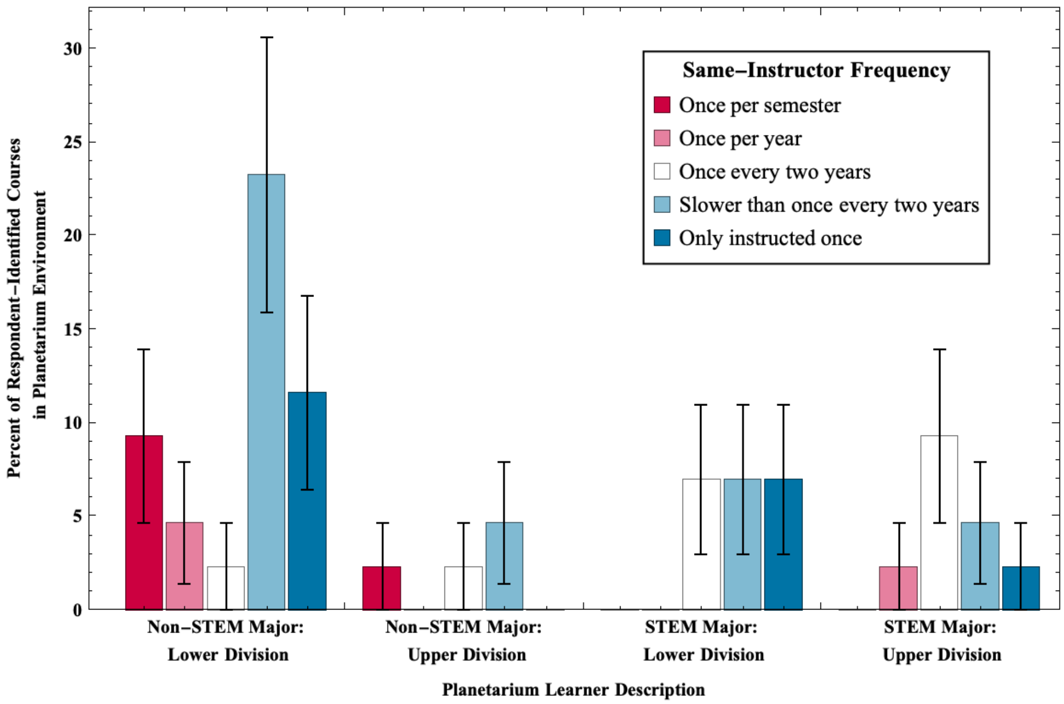
Figure 1. Planetarium users' ($N = 26$) self-identified familiarity with three DBER fields commonly investigating planetarium learning during the survey portion of this study. Standard counting error ($\sigma_k = \sqrt{N_k}$), expressed in percent-equivalent, is assumed in each bin. Users are generally familiar with physics and astronomy education findings, but generally unfamiliar with planetarium education findings.



Expectedly, non-users rated mostly as "very unfamiliar" with all three education fields (not included in Figure 1), suggesting non-users experience a complete detachment from the planetarium as a formal researched educational venue. Users rated greater familiarity with the three fields, particularly with astronomy education. However, the lower measure of "very familiar" and "moderately familiar" counts in the planetarium education category compared to the physics education and astronomy education categories could suggest that user faculty are more likely to be abreast of education research findings derived from the regular classroom or laboratory setting than the planetarium, specifically. This distinction could be of great importance for future endeavors in the planetarium space. Instructors are likely to pay greater attention to education research findings that would have the greatest impact on their usual instructional practices, such as those found in the regular classroom setting where most of their instruction would occur (e.g., active-learner/peer-instruction strategies, iClickers, etc.). Instruction in the planetarium space is not the commonplace locale of collegiate instruction, so innovations originating in that setting might not make as great an impact on users' pedagogical considerations as one originating from the lecture hall. By extension, users could be transferring their classroom instructional practices directly into the planetarium without consideration of whether those practices would be as impactful or achieve similar outcomes in the planetarium environment.

Users were also asked to identify with what frequency they teach a particular course in the planetarium (e.g., "ASTRO 101" or "PHYS 301"). The frequency with which instructors taught these courses is denoted by the colors in the legend of Figure 2. Courses are separated by learners' educational track (Non-STEM/STEM major) and course difficulty (lower/upper division) along the horizontal axis. Responses suggest that a particular planetarium user is not instructing the same course (and accompanying body of content) in the planetarium environment at frequent intervals (once every two years, or slower, on average for the four learner descriptions).

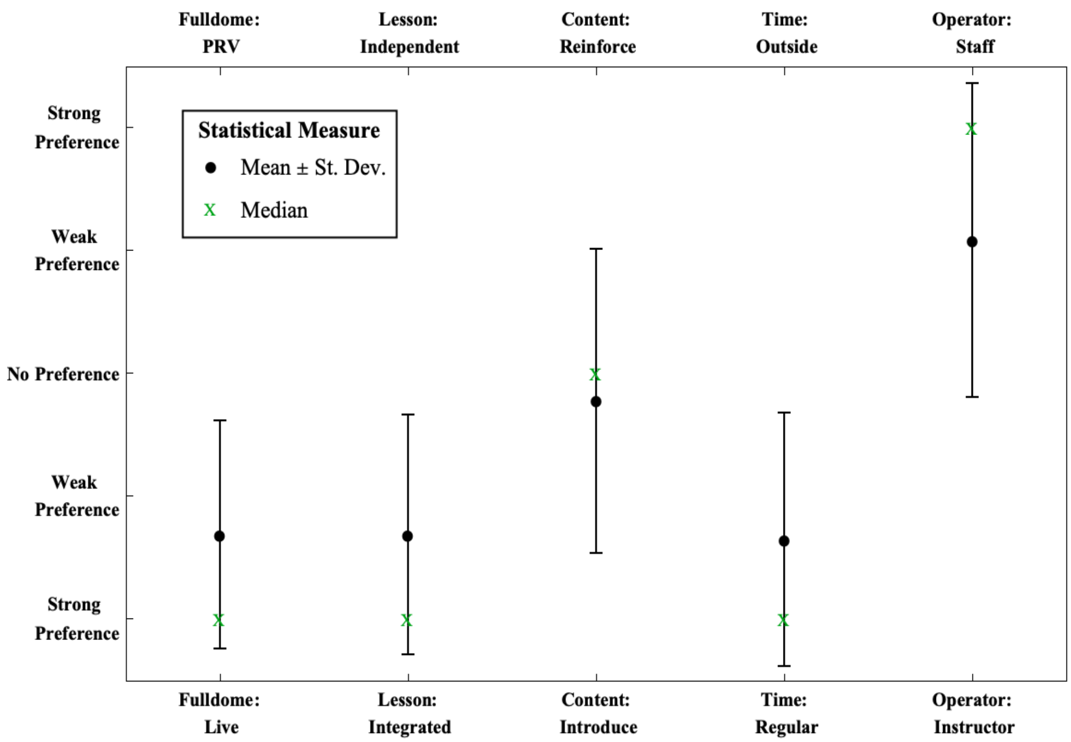
Figure 2. Distributions of the frequency of instruction of planetarium classes by the same instructor between 2016--2019, as reported by user faculty, separated by learner education track Non-STEM Major / STEM Major) and course division (Lower / Upper). Standard counting error ($\sigma_k = \sqrt{N_k}$), expressed in percent-equivalent, is assumed in each bin. Forty-three unique instances of a particular course were described by respondents. Response trends suggest that planetarium use for a particular instructor teaching a particular course is rather infrequent, further suggesting that planetarium use (or any changes thereto) do not propagate quickly within this body of planetarium instructors.



Such a slow rate of repetition could suggest that instructors might maintain a "default" presentation style in the planetarium, possibly the presentation style maintained in the classroom environment, as they are so rarely forced to contend with the same or similar lesson delivery. Additionally, once instructors have established a particular repertoire of planetarium worthy content (discussed above under "Construct 1"), the slow rate of repetitions might suggest that instructors would be unlikely to consider other content presentations in the space. Part of the "calculus" of the planetarium environment (discussed above) is preparation time for a particular lesson; if planetarium instruction occurs so infrequently, instructors might not consider innovating upon their established repertoires due to the time commitment necessary. A possible exception to this might be instructors who instruct similar, but not identical, courses with greater frequency. An example of this might be two courses which overlap in presented content but are distinguished from one another only by the presence of a laboratory requirement in one that is not shared in the other.

Reflecting back upon our discussion of the user response code L under "Construct 1" (Table 5), we contend that these data not only indicate that the planetarium environment is viewed by our respondents as the province of lower division courses, but that this view holds little regard to those learners' education headings. If one were to express the percentage of respondent-identified courses in Figure 2 as absolute counts, 31 of the 43 courses were lower division, with the remaining 12 being upper division. Moreover, 22 of the 31 lower division courses were for non-STEM majoring learners. In light of our interviewees' discussions concerning classroom and planetarium materials, the implied rigor of upper division courses would suggest that the planetarium is not considered to be as valuable to those learners as regular classroom instruction. As was discussed in the interview portion of Everding and Keller (2020), this supposition about more experienced learners not "needing" the planetarium space may not be an advisable position. Combining this inference with the discussion in the previous paragraph, it may be the case that if an instructor's "default" presentation style did not include upper division or STEM majoring learners when it was first formulated, it might be unlikely to ever consider including those learners in a future presentation style.

Figure 3. Responses of users ($N = 23$) regarding their preference towards particular facets of lesson delivery in the planetarium. Statistical measures presented are specified in the legend. Distributions within the five facets (described further in text) are suggestive of faculty who prefer planetarium lesson delivery to closely resemble classroom lesson delivery, excluding the operation of the planetarium projectors where preference favors a third-party operator. Skewed locations of the mean and median suggest heavy preference towards one end of each dipole, except for the "Content" facet.



To establish how users preferred their planetarium lesson to proceed, respondents were asked to select their preference towards a particular presentation mode with each of five presentation facets, each facet being presented as a dipole choice between two approximately exclusive end members. These five presentation facets concern the following: (1) whether the fulldome projector is used for pre-recorded video (PRV) content or live presentation content; (2) whether a planetarium lesson is independent or integrated into an instructor's semester-long lesson plan; (3) whether content is introduced or reinforced from previous introduction in the planetarium; (4) whether lessons occur during the regular class meeting time or outside the regular class meeting time; and (5) whether the planetarium systems like the projector are operated by the instructor themself or by a member of the planetarium staff.

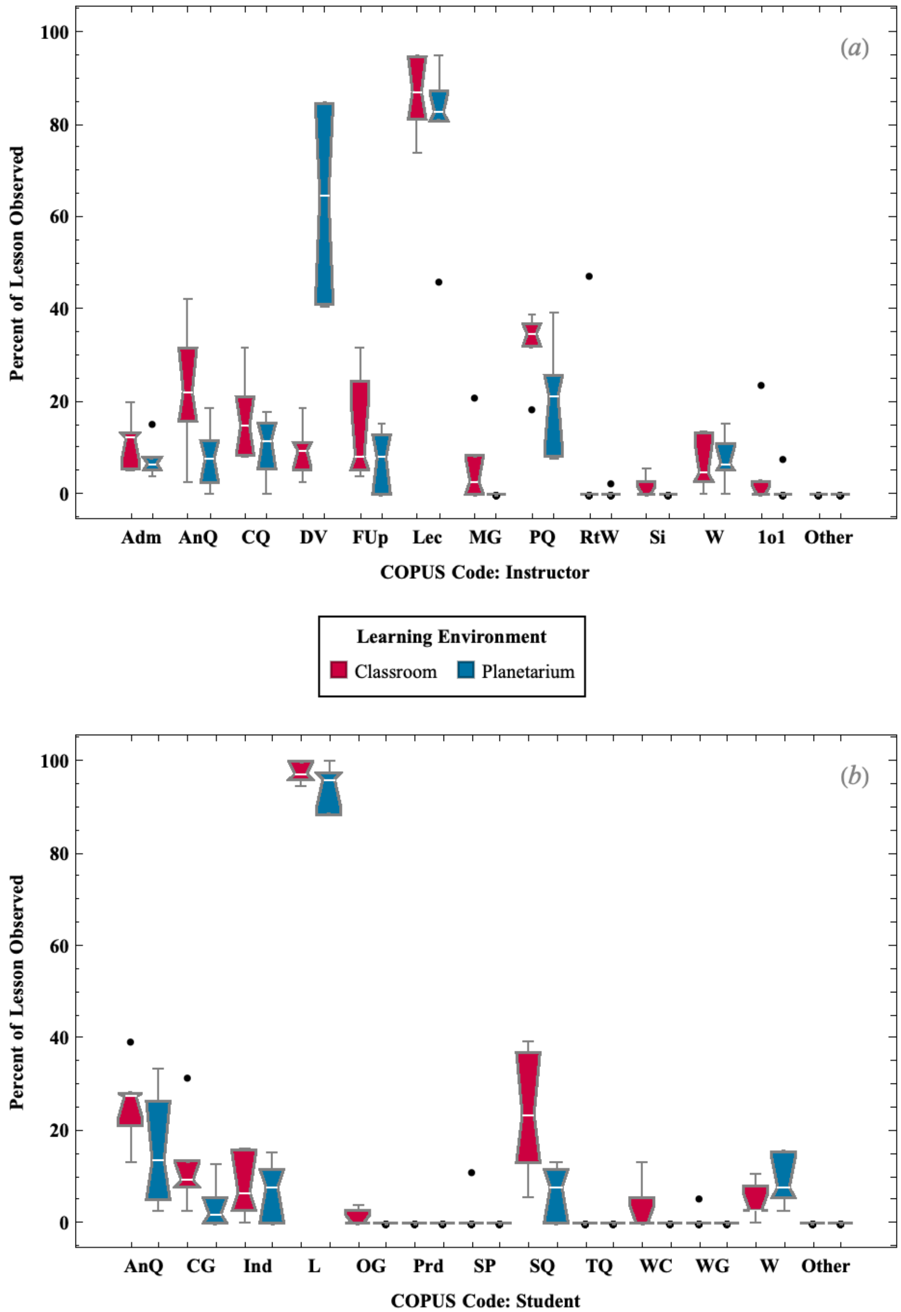
The distributions of preference counts are shown in Figure 3. Means (black points with standard deviation bars) and medians (green X's) were calculated by assigning an integer value ranging from -2 to +2 to each of the preference values within each facet. For example, under the fulldome facet, a strong preference towards "live" would have a score of -2, a weak preference would be -1, no preference would be 0, a weak preference towards PRV would be +1, and a strong preference towards PRV would be +2. Both means and medians show strong polarization for four of the presented facets (fulldome, lesson, time, and operator) and minimal polarization for the fifth (content). The disjoint locations of the means and medians demonstrate that most of the counts in each facet are in one of the two extreme ends ("strong preference"), except for the minimal polarization in the content facet.

In a large collegiate classroom setting, live presentation (that is, presentation made by a real person in the room with the learners) is likely the commonplace mode of instruction (Stains et al., 2018). Semester-long lesson plans typically schedule out every week of instruction as part of an integrated whole to reach the course's semester-long learning goals-few instances of independent or disjoint lessons confronting non-assessable content would be expected. Content in the classroom is both introduced and reinforced throughout the semester. Lastly, the time the instructor and their learners meet in the classroom is usually defined by a collegiate administration, so that the lesson presented therein has no schedule conflicts with other courses' lessons. The distribution of preferences in Figure 3 strongly aligns with this "typical" classroom description and suggests that as a practical matter user faculty prefer planetarium lessons that closely mirror their classroom counterparts, with the exclusion of the operator facet. In this case, there is a strong preference for having a separate operator in the planetarium to control the projector system while the instructor presents-this preference is in distinct contrast to the classroom setting where the instructor is usually both the presenter and the projector operator. The distribution of preferences also suggests that the planetarium is perhaps not seen as a unique learning space in its own right but is instead seen as an augmented or alternate classroom.

Discriminating the Two Environments: COPUS Data

Further insight into this supposition is gained by directly examining the distribution of COPUS behaviors in the two environments recorded during our joint classroom/planetarium observations. Because COPUS codes are recorded every two minutes, it is possible for multiple behaviors to be recorded within the same time window, even when such behaviors would be indicative of distinctly different instructional or learning modes. For example, in our planetarium observations, the instructor codes Lec (instructor lecturing or presenting content) and DV (demo/video) often coincide with one another in the same two-minute observation window-such dual coding is exemplary of an instructor lecturing on a piece of material and then showing a short simulation on the planetarium dome pertaining to that material or showing a separate simulation to introduce the next discussion in the space. The percent-of-lesson data distributions presented in Figure 4 were calculated as follows: (1) for each individual instructor or individual student group, each particular behavior was tabulated based on how many two minute observation windows that particular behavior was recorded using COPUS; (2) each particular behavior tabulation was then divided by the maximum number of possible two minute observation windows available for a given observation period and multiplied by 100%, thus producing a percent-of-lesson value for each behavior; and (3) the percent-of-lesson values for each instructor and group of students was plotted for the two separate environments, producing the 26 pairs of data distributions shown in Figure 4.

Figure 4. Distribution of COPUS code counts for instructors (a) and students (b), expressed as percentages of the observed lesson for the two environments (legend). A description of box plot rendering can be found in text under "Data & Analysis." In each pair of boxes, the left one is the measurements from the classroom (red) and the right one is the measurements from the planetarium (blue). Results suggest that planetarium learning environments are measurably more passive than their classroom counterparts, typified by the reduced percentages of active-learner indicator behaviors ((a): AnQ, PQ; (b): AnQ, CG, SQ); see text for full description of codes.



The similarities and differences between the two environments were qualitatively apparent based on the location and spread of either environment's percent-of-lesson distributions; however, to qualify the differences between the two environments beyond a simple qualitative judgement of these distributions (Figure 4), t-test calculations for each of the 26 distribution pairs were made, using significance levels (α values) of 5% and 10% as the calculation cutoffs when comparing p-values. T-tests were run against the null hypothesis that the difference in means between the two environments for a particular group's behavior distribution was zero. We remind the reader that the COPUS data in this study represent six faculty instructors and their entire corresponding student bodies ($N = 6$), so statistical inferences from these small data sets are not as robust as inferences garnered from a larger set of data. Results of the tests suggested significant differences between the expressions of the instructor behaviors AnQ (instructor answering student questions; $p = 0.04$), DV (instructor using demonstration or video; $p = 0.001$), and PQ (posing questions to class;$p = 0.06$) and expressions of the student behaviors CG (student clicker group(s); $p = 0.08$) and SQ (student question to instructor;$p = 0.03$). All other differences between behavior expressions were not significant. AnQ, PQ, CG, and SQ were expressed in greater percentages in the classroom, and DV is expressed in a greater percentage in the planetarium. On the whole, our COPUS observations do not fit perfectly with the lesson code archetypes presented by Lund et al. (2015) nor the actor/action code archetypes in Smith et al. (2014). As a group our observed classroom lessons were somewhere between "Socratic with slides" and "Limited Peer Instruction with slides" with a larger percentage of the Lec behavior (Lund et al., 2015). Similarly, our observed classroom actors could be described as presenting instructors and receiving students with some smaller contributions from interactive or reformed practices (Smith, Vinson, Smith, Lewin, & Stetzer, 2014).

The four classroom-favoring behaviors are indicative of greater interpersonal communication between the instructor and their students, suggesting a more interactive or active-learning environment (Felder & Brent, 2009). Compared to the archetypes of instructors and students presented in Smith et al. (2014), these behavior measurements are also indicative of a guiding instructor and working/conversing students. The AnQ/SQ behavior pair especially highlights this, as the interaction described by these two behaviors can be directly interpreted as the learners asking more questions (and the instructor similarly answering) in the classroom compared to the planetarium. At the less significant level, the PQ instructor behavior further supports a more instructor-focused environment in the planetarium, suggesting that instructors pose fewer verbal questions to their classes. Similarly, the difference in CG behavior suggests that when questions are asked to groups of learners using a Clicker, planetarium lessons are less likely to involve peer-to-peer or think-pair-share interactions incumbent with a Clicker question. The lower measure of CG in the planetarium, without a corresponding drop in CQ (instructor presenting Clicker question) or Ind (student responding to Clicker individually), further suggests that while Clicker questions are used, the content or difficulty of such questions has been chosen only to quickly scan the learners' understanding of a concept without an expectation of meaningful discourse after the question is completed. Clicker use of this kind does comport with student attitudes about the devices (Sevian & Robinson, 2011), however it may also represent a lost opportunity for instructors to engage with their learners instead of "just checking" that everyone is still responsive. Clicker use can be a challenging process for college classrooms and creating and executing effective Clicker questions is a non-trivial task for instructors under the best circumstances. Our COPUS measurements may suggest that Clicker question items need to be refined for the planetarium environment using a framework appropriate to the environment that takes into account the darkened conditions and restrictive seating.

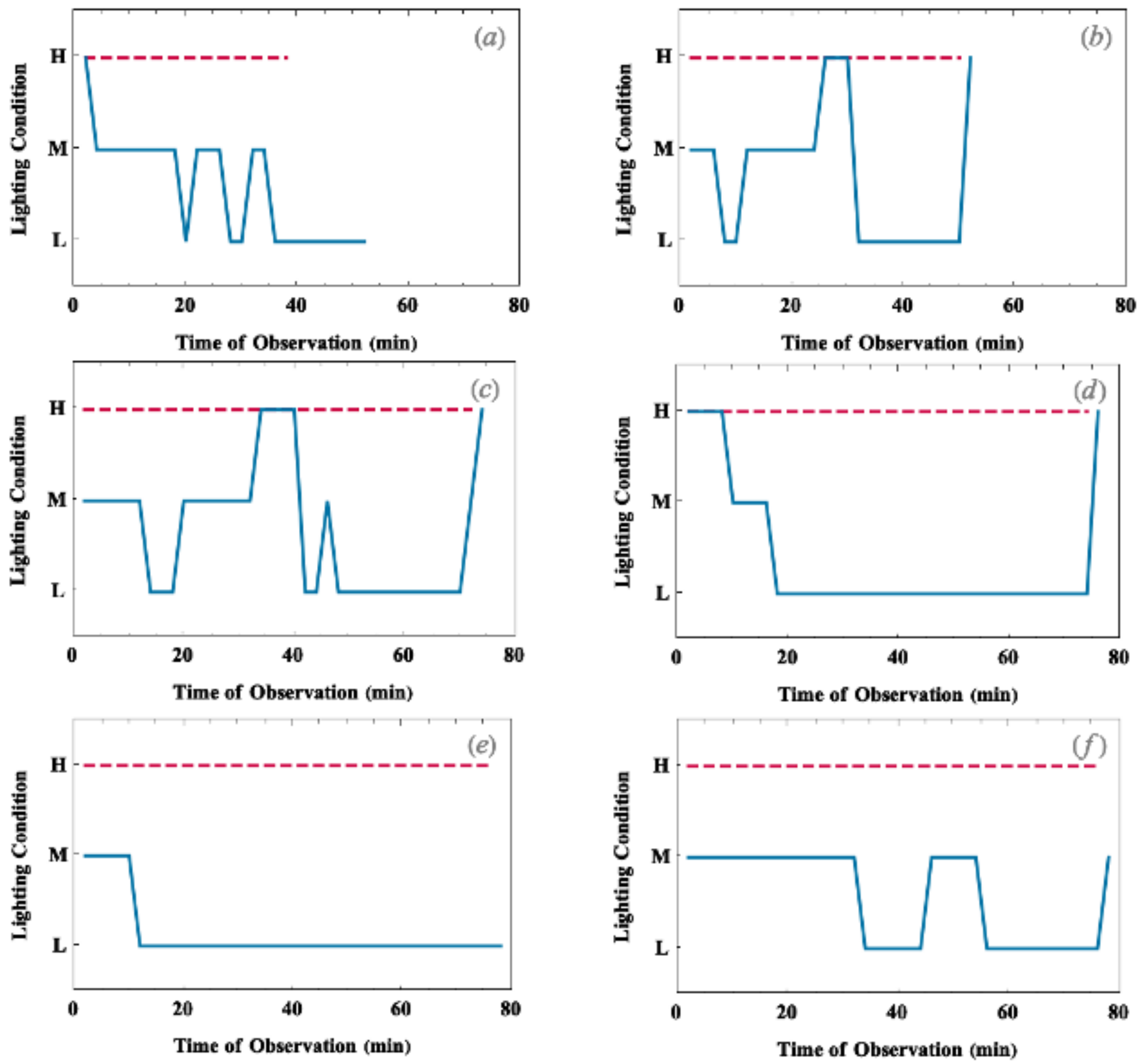
The single planetarium-favoring behavior is indicative of a more visually compelling environment, one in which instruction is supplemented by significant immersive visual aids via the planetarium dome. As described in "Methods & Investigation," the DV code is used to identify when the planetarium projectors are "on," and the percent-of-lesson counts in Figure 4 show that during a lesson in the planetarium, roughly 65% of the lesson is presented using the planetarium's projectors. When compared to the roughly 10% occurrence of DV in the classroom, the percent-of-lesson counts clearly demonstrate a sizable shift in presentation style in the planetarium, from one relying on few visual aids in the classroom to one using them almost two-thirds of the time. Moreover, the variance within the planetarium DV code percentages propose that there may be a very wide range or opinions among users as to what amount of a lesson "needs" to be held with immersive visuals. Even so, we note the lack of significant difference between the two environments of instructor code Lec (instructor lecturing or presenting content) and student code L (listening to lecture or taking notes), which occurs roughly 85% and 95% of the time during a lesson, respectively. This apparent reliance on lecture-based, didactic instruction as the primary means of discourse is not unexpected, given the large class sizes and instructor-described barriers to movement throughout the planetarium space (Stains et al., 2018).

Taken together, these data suggest that in the planetarium, instructors are lecturing and learners are listening just as they do in the classroom. Combined with our survey data concerning instructor presentation preferences in the planetarium (Figure 3), the large lack of COPUS differences (excluding those discussed above) is illustrative of a planetarium learning environment that is by-and-large procedurally similar to the classroom learning environment. However, the differences in interactive learning behaviors and the instructor code DV suggest that a trade occurs when learning moves into the planetarium environment: the loss of interactive learning in exchange for more time in a visually immersive environment to supplement lecture material. Such an exchange could be of great significance, as it would indicate that instructors are knowingly choosing to give up some of the advantages of interactive pedagogies to make use of the planetarium's immersive presentation advantages.

Both immersive and interactive instruction are well documented to be superior modes of instruction compared to their personal counterparts. Immersive planetarium instruction is routinely shown as assisting learners achieve greater gains, both immediately after instruction and over time (Yu et al., 2016; Yu et al., 2017), when compared to instruction using static or two-dimensional content presentation (like a textbook figure). Similarly, learner-centered techniques have demonstrated a potent advantage over older instructor-centered techniques (Fagan et al., 2002; Prather et al., 2009; Freeman et al., 2014) that there have been calls to eliminate instructor-centered pedagogies from collegiate use entirely (Freeman et al., 2014). We conceive of no reason that interactive instruction in the immersive learning environment should not still reap at least some of the demonstrable benefits of both pedagogical strategies. However, we would also comment here about the findings in Andrews, Leonard, Colgrove, and Kalinowski (2011), who showed that implementations of active learning strategies do not always correspond to learning gains in collegiate settings. Faculty who are not active DBER researchers do not always approach active-learner strategies with the same care and nuance to elicit the strategies' maximal benefits (Andrews et al., 2011). Since the expression of active learning strategies were reduced in the planetarium (as measured using COPUS), we are skeptical of the impact of active-learning strategies when used with such low frequency in that setting. That is to say, we are skeptical toward the benefits of using active-learning strategies in potentially "token" amounts. Does the class benefit from including a single Clicker question and discussion, or would more time in the immersive visual environment have been a better use of time? We are also unsure as to what the appropriate "mix" of active-learning and immersive pedagogical strategies should be and the variance in the planetarium DV code (Figure 4) might also suggest that planetarium instructors may not have a well-defined sense of such a mix either. However, narrowing the scope of this question would most likely require longitudinal observation campaigns examining multiple instances of different course content, which are beyond the scope of this work's "snapshot in time" approach. We revisit this possibility of future work below, under "Theoretical Synthesis & Future Work."

Finally, we turn our analysis to the environments themselves and how the classroom and planetarium spaces are distinct entities. During the course of our observations, the COPUS engagement framework was used to record illumination conditions in the observed environments (described above in Table 3 and in supporting text). Lighting conditions throughout the 12 observations demonstrated no pattern of interest in either environment (Figure 5). In the classroom environment (red dashed lines), the lighting condition never changes-all entire classes are held in high lighting conditions throughout. In the planetarium environment (blue solid lines), a variety of lighting conditions were recorded with lighting variability showing as little as one shift (panel (e)) to as many as seven shifts (panel (c)) in ambient illumination. In spite of the variance shown in our six planetarium observations, no real correspondence between lighting shifts and COPUS behaviors was observed-changes to lighting conditions appear to be too instructor-specific. Generally, lighting changes occurred when an instructor was attempting to engage interactive or active-learner strategies like a clicker question (CQ) or during a question/answer session (Figure 5, panels (a)--(c)). However, not all instructors raised the lighting conditions during occurrences of these behaviors and left the lighting conditions on low once the class had gotten underway (Figure 5, panels (d) and (e)). Excluding brief windows at the beginning and end of instruction (to facilitate learners finding/leaving their seats) and two periods in panels (b) and (c), lighting conditions never exceed medium, which in the observed planetarium is relatively bright, but low energy red lights around the perimeter of the planetarium dome (Table 3). These data did not point to instructors' consideration of lighting conditions towards a particular pedagogical strategy, per se, but rather towards maintaining a minimally disruptive lesson delivery. Lights were brought up-and-down only as necessary to facilitate the lesson delivery, but not always for all observed instructors. Examples of this included: bringing up lights to heighten visibility during lecture, bringing up lights to allow students to move to their seats or the door, and bringing lights down to enhance the visibility of the star projector or fulldome projectors. Of these examples, only the last one was rigorously observed in all six instructors.

Figure 5. Time series of the lighting conditions during the COPUS observations (classroom: red dashed lines; planetarium: blue solid lines). Lighting conditions (H, M, and L) are described in Table 3. Classroom lighting shows no variability during the observed classes. Planetarium lighting shows variability, but no robust trend across the six observations is evident.



Uniting these discussions, we confront our second research construct: discriminating between the classroom and planetarium environments. By-and-large, the two environments shared broad pedagogical process overlap, as is measured by our COPUS observations (Figure 4), survey responses (Figure 3), and interviews (Table 6). Instructors using the planetarium presented content with much the same procedure used in the classroom setting; however, COPUS behaviors indicative of interactive or active-learning strategies were reduced. Interview responses placed more value on the classroom setting for cognitively rigorous course materials, such as those perceived as needing notes, calculations, or discussion. The planetarium is seen as helping learners via the immersive and animated visuals, providing visualization scaffolding not available in the classroom setting. However, both survey responses and interviews suggest that the cognitive aid of the planetarium is secondary to the affective goals, like engaging learners with material via the spectacle of planetarium presentation. Survey responses concerning instruction frequency (Figure 2) suggest that the planetarium setting was perceived as more conducive to lower division learners. Coupled with the emergent cognitive-classroom/affective-planetarium value system described by users, planetarium use at the upper division, though clearly possible, might fail to achieve more widespread use as the environment is not perceived as helpful towards aiding experienced learners to meet course content goals.

Limitations Of This Study

Lastly, we highlight the limitations of this study and their potentially adverse effects on our findings. First, the planetarium considered in this study is a partial outlier when one considers all the other planetariums available in the United States. The classes observed in this planetarium were quite large (~100-200 students) when compared to the median class size of ~30-40 students measured in Everding and Keller (2020). Additionally, the availability of audience response systems like Clickers in planetariums is not widespread, making this planetarium an outlier in interactive technology availability. This limitation is not as restrictive, given the portability of Clicker technology, but other studies that examine pedagogical implications of the planetarium may or may not have an audience response system available.

Secondly, this study relied on a "snapshot" approach to classroom and planetarium instruction, by using a single observation of each instructor in each environment. Such a strategy could unintentionally mischaracterize how instruction unfolds in either environment, however we believe we have reduced that danger by considering observed trends of the group of instructors as opposed to individual instructors. Additionally, the instructors in this study all made efforts towards using reformed practices, something which may not be commonplace on other campuses or collegiate planetariums. Moreover, the observation portion of this study had just six participants. As was discussed under "Construct 2," our statistical comparisons of behavioral differences should be taken with some care, as the low number of observation points makes rigorous statistical inference possible, but not as strong as if we had observed a larger number of instructor participants.

Finally, this study does not include a student/learner survey or interviews concerning either environment. Only COPUS data concerning the students observed and instructor-relayed information has information about the learners. The implied limitation is obvious-this study has limited information concerning the other half of the collegiate learning experience, leaving us to rely on alternate data implications, rather than relying on the learners themselves. However, it does represent a missing piece of information that a future study concerning the planetarium environment would be advised to make in a more direct fashion.

THEORETICAL SYNTHESIS & FUTURE WORK

Using the LEPO framework (Phillips et al., 2012), collegiate planetarium learning is attained in two complementary formal environments: the planetarium setting itself and the regular classroom setting. The learning processes in both environments share a high degree of similarity based on our COPUS measurements and can be broadly described as mostly instructor-centered with noteworthy inclusions of learner-centered pedagogical processes. Classroom processes make greater use of interactive and active-learner strategies like Clicker questions, peer-to-peer instruction, and group interactions. Assuming the classroom process template is the "usual" state of affairs, planetarium processes make predominant use of immersive visualization strategies at the expense of interactive and active-learner techniques used in the classroom. The reason for this exchange is the perceived incompatibility of the planetarium setting with interactive and active-learner techniques which rely on a degree of mobility by the instructor or their learners which is not feasibly attained in the planetarium theater. Moreover, the heavy investment in visualization-based presentation may have necessarily required a reduction in other pedagogical modes due to the limited time available for a particular class in the planetarium. Outcomes in the two environments show a weak preference for an affective-favoring planetarium and a cognitive-favoring classroom.

Further observations with a larger number of instructors and observed lessons using COPUS would better refine the implications of this study's "snapshot" approach at investigating planetarium use. Longitudinal observation campaigns following the same faculty instructor (or group of instructors) over multiple planetarium visits would provide additional points of observation as well as demonstrating how or if planetarium use changes over the course of a given academic term. We might propose to follow the advice from Smith et al. (2014) and unite the investigative power of COPUS with an instrument like the Teaching Practices Inventory (TPI), developed by Wiemann & Gilbert (2014), but modified to include planetarium-specific aspects. Such an observation/inventory combination would offer planetarium users or content developers a window into instructors' use of the planetarium space while also generating externally observed use practice catalogues with COPUS (Smith et al., 2014). Additionally, by incorporating both instructor opinions and experience into such a study, it might be possible for any pedagogical innovations created as a consequence of such studies to diffuse more easily to other instructors, alleviating some of the slow pace of collegiate practice reforms (Henderson & Dancy, 2008; Oleson & Hora, 2014).

Our analyses suggest that there is a shift in pedagogical strategies between the two environments, with the classroom embracing more active learning strategies than the planetarium, which itself embraces immersion-visualization strategies. These two points leave us with two questions concerning if such an apparent exchange of strategies is necessary: (1) can the benefits of both interactive and immersive strategies be achieved in the planetarium environment; and (2) what is the correct "mix" of the two strategies to achieve the greatest learning outcomes? We suspect that the answer to the first question is "yes" (Sumners et al., 2008), but we are uncertain as to the second. Future studies might focus their efforts on investigating how the effects of both pedagogical strategies can be maximized for formal collegiate learning, similar to the hybridization approach discussed by Swap and Walter (2015).

CONCLUSION

A mixed-methods investigation combining an online survey instrument and in-class COPUS observation protocol campaigns has been completed as a western American university. Twenty-six faculty members with planetarium experience and 87 faculty members without planetarium experience completed an online survey measuring the characteristics and procedures of their planetarium use, or lack thereof. Additionally, six user faculty were observed in both the formal collegiate classroom and planetarium environments using the COPUS observation protocol (Smith et al., 2013), and were then interviewed about their classroom and planetarium instructional experiences.

Non-user survey responses suggest the existence of an ineffective or inefficient communication channel between non-user instructors, who might maintain an outdated conception of the planetarium's capabilities, and planetarium professionals including planetarium staff and content developers. Using the innovation-decision process tree presented in Rogers (2003), our analysis suggests that the first (knowledge) and second (persuasion) communication channels might not be effectively leveraged to inform non-user instructors of the potential materials and instructional benefits of the immersive planetarium space.

Survey responses from users suggest that planetarium lessons occur for both STEM majoring and non-STEM majoring learners, but said learners are mostly in the lower division. Content examples provided by respondents suggest that users attach value to the planetarium for both its older display capabilities (e.g., sky motions or Moon phases) and its newer display capabilities (e.g., immersive Solar System orrery or navigable galaxy model). Described learning outcomes in the planetarium and classroom environments suggest a weak dichotomy between the two, with the planetarium being valued as an affective outcome-stressing environment and the classroom as a cognitive outcome-stressing environment. Crucially, planetarium lessons are not considered as isolated or "one off" occurrences and are seen as integrated into a course's overarching curriculum.

Interview responses from users suggest the existence of a broad framework for what makes a particular body of content "planetarium worthy," and thus worth the investment of time in the planetarium setting. Worthy content is visualization-based curricular materials that can be presented in both the classroom and planetarium settings. Presentation of worthy content in the planetarium leverages that space's projection capabilities to provide scaffolding aid for learners via immersion visuals and animation. Presentation in the classroom instead leverages that space's structural advantage promoting "regular" classroom activities like active-learner strategies and note-taking. Worthy content is thus perceived as needing student confrontation twice: once in a style that stresses a visual representation and once in a style that stresses a more abstract representation. The reported rate of same-instructor-same-course frequency in the planetarium combined with interview responses concerning planetarium lesson preparation suggest that user faculty may be unlikely to innovate outside an established pattern of planetarium worthy content.

Additionally, interview responses suggest that the planetarium space itself is a hindrance to the application of active-learner strategies as the darkened environment and seating arrangements make navigating through the planetarium space difficult for instructors and learners.

COPUS observational data comparisons between the two environments suggest that planetarium instruction is broadly similar to classroom instruction, typified by a mostly instructor-centered lesson delivery with inclusions of learner-centered behaviors. The planetarium environment is the more passive of the two, based on the differences between behaviors typifying interactive or active-learning strategies measured by COPUS. Instructors exchange interactive instructional practices for immersive visual presentations when learning moves from the classroom environment to the planetarium. Use of immersive visualizations is varied across the observed planetarium lessons, with immersive fulldome content being shown approximately 40%-85% of the observed lesson. However, the implementation of interactive strategies does not reduce to zero in the planetarium, suggesting that instructors are attempting to merge the benefits of both interactive and immersive strategies while making as efficient use of the planetarium space as possible.

ACKNOWLEDGEMENTS

The authors would like to express thanks to this study's faculty participants, with special acknowledgement of our six interviewees who allowed us to observe their classes. We also extend our thanks to the University of Colorado Boulder's ASSETT office for their assistance in training this study's COPUS observers.

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